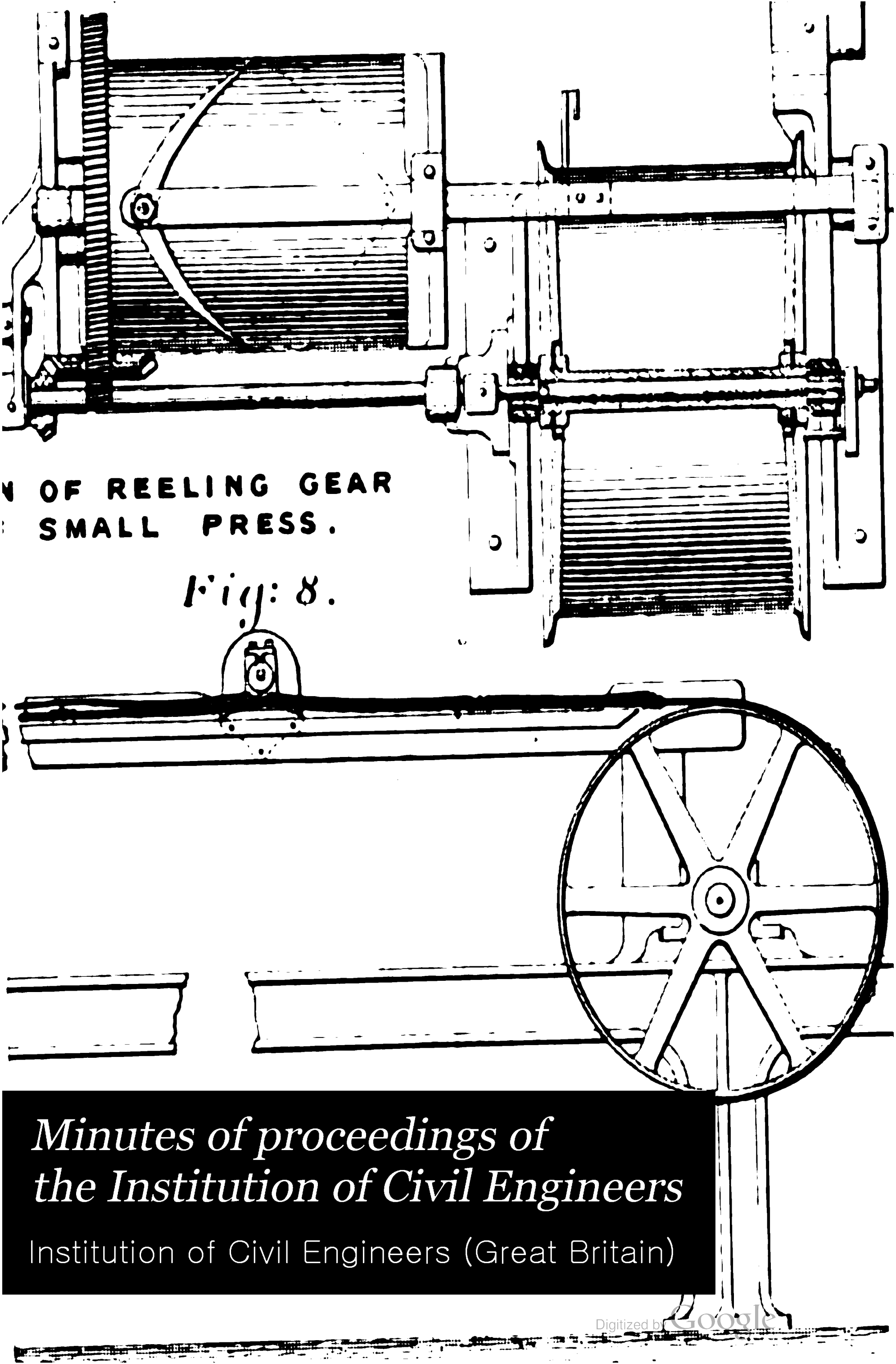

Minutes of proceedings of the Institution of Civil Engineers

Institution of Civil Engineers (Great Britain)

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXXXII.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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CORRIGENDA.

Vol. cxxxi. p. 123, line 24, *for* "Mr. JOHN DAVIES, of Derby," *read* "Mr. ALFRED DAVIS."

" " p. 208, 4th line from bottom, *for* "coal" *read* "cool."

" " p. 335, lines 16 and 17,

for
$$v = \frac{w\,l^3}{8\,(1 + C)\,E\,A_1}\left[\frac{2\,l^2\,C}{3\,h^2} + 1\right]$$
$$= \frac{w\,l^3}{8\,(1 + C)\,E\,A_1}\left[13 + 1\right].$$

read
$$v = \frac{w\,l^3}{8\,(1 + C)\,E\,A_1}\left[\frac{5\,l^2\,C}{8\,h^2} + 1\right]$$
$$= \frac{w\,l^3}{8\,(1 + C)\,E\,A_1}\left[12{\cdot}5 + 1\right].$$

" " p. 335, line 19, *for* "to $\frac{1}{13}$" *read* "to about $\frac{1}{13}$."

" " p. 337, line 4,

for
$$M_o = -H_1\,\frac{w_o\,l^2}{12}\cdot B - \frac{w\,l^2}{64}$$

read
$$M_o = -\frac{w_o\,l^2}{12}\cdot B - \frac{w\,l^2}{64}.$$

" " p. 483, line 7, *for* "L'Éclairage Électrique, 1897, p. 522," *read* "Philosophical Magazine, March, 1897, p. 161."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1897-98.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

14 December, 1897.

SIR JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S., President, in the Chair.

(*Paper No. 3074.*)

"The Great Land-Slides on the Canadian Pacific Railway in British Columbia."

By ROBERT BREWSTER STANTON, M.A., M. Inst. C.E.

THE great land-slides which have caused so much trouble and expense in working the Canadian Pacific Railway, since the opening of the line in 1885, occur on the banks of the Thompson River, about 41 miles above its junction with the Fraser River and 197 miles east from Vancouver, the western terminus of the railway, Fig. 1, Plate 1. Within a distance of somewhat over 5 miles there are seven large land-slides, all of the same nature, and six crossing the railway line, as well as smaller slips, Fig. 2. About 20 miles further down the river, at a point opposite Spence's Bridge, there is a similar large slide.

The railway occupies the east and south-east bank of the river, at an elevation between 50 feet and 80 feet above low-water level, and follows closely, with one exception, the contour of the river bank. At about 200 miles from Vancouver the railway passes through the Black Cañon Tunnel. This portion of the Thompson River, for a distance of about 20 miles, traverses a gorge about 5 miles wide at the top, and about 2,000 feet deep, with hills and higher ranges rising back on each side to elevations between 5,000 feet and 7,000 feet. In the middle of this gorge the river runs in an inner gorge, with sides between 50 feet and 150 feet above low-water level and close to the river. There is but little bottom land near the river. The surface rises from the water's edge in benches and terraces, varying in height between 30 feet and 200 feet, and extending to a general altitude of about 1,800 feet, or about 1,000 feet above the river. The land

rises beyond in broken slopes interspersed with hills and peaks. The terraces and slopes are cut by many dry gulches and small streams draining into the river. The largest of the benches, and the lowest flat in this neighbourhood is occupied by the town of Ashcroft.

The terraces of these greater valleys are cultivated for raising winter food for the cattle that range the higher valleys and the open timber of the lower hills, and for raising garden, field and orchard crops for local consumption.[1] Artificial irrigation is necessary, there being no natural growth in the lower valleys, such as those of the Thompson and the Fraser Rivers, except bunch grass (*agropyrum tenerum*) and a few single trees, with stunted bushes. Systems of irrigation have therefore been established by bringing the small mountain streams on to these tracts. The water of the river, running at the bottom of a somewhat deep gorge, is not available; so the smaller streams and lakes of the adjacent mountains are used as the sources of supply, in some instances supplemented by artificial lakes or storage reservoirs. The water is carried on to the land by small rudely-constructed ditches, built almost entirely by the farmers who occupy the land.

The Black Cañon of the Thompson River is a narrow gorge about 1 mile in length, where the river has cut its way through an uplifted ridge of black shale, which was raised in the bottom and parallel with the course of the valley. On its eastern side there are two hard sandstone points next to the river. The railway passes through one of these by a short tunnel, and through the northerly one by an open cutting, exposing the greenish hard sandstone rock and the position and dip of the overlying shale. The two greatest slides are situated, one north, the other south of these points, Fig. 3, Plate 1. At both places the country originally sloped up from the river in a series of benches or terraces to the first line of hills. The south slide has an extreme length of 1,880 feet along the railway, and an extreme width back from the river of 1,575 feet. It is of somewhat irregular form, with a semi-circular outline at the back, and covers an area of 66 acres. The north slide has a maximum width at its widest portion of nearly ½ mile, and a length back from the river approaching ¾ mile, with the same semi-circular back line. It is of irregular form, and extends over an area of 155 acres. The height of the first bench next to the river, in both cases, was originally about

[1] "British Columbia: its Present Resources and Future Possibilities," published by direction of the Provincial Government at Victoria, B.C.

80 feet above low-water level. The land then rose in successive levels to a height, on the south slide, of 400 feet to the bench at the top, or back edge, where the cave-down broke off the solid ground, and in the case of the north slide it extended to the third higher bench 500 feet above the river. It is impossible to ascertain at what depth these enormous masses of earth and loose rock broke, or in other words, the depth of the plane on which the mass moved towards the river; but it is estimated that at the back edge of the south slide the break fell almost vertically for a distance of over 300 feet, and on the north slide perhaps over 400 feet.

The terraces on each side of the valley of the Thompson River along this section consist of the soil on the top of each bench of light sandy loam to the depth of between 1 foot and 8 feet. Below, in places, is found between 3 feet and 10 feet of clean coarse river sand. Next occurs loose and nearly clean stratified gravel and boulders, and below this a partially cemented gravel with larger boulders. The material which holds together the gravel and stones of this formation is boulder clay, a porous arenaceous clay silt, through which water passes freely, yet which, in a dry state will stand in vertical walls to a considerable height. It extends to a greater depth on the higher terraces; in places it is perhaps 500 feet deep. The boulder clay is here found in two forms: in its original form as first laid down, and, especially upon the lower benches next to the river, in a secondary or re-arranged form. Under the lower benches, particularly under the slips, there is a deposit of silt or imperfect clay, which shows in places to a depth of between 50 feet and 200 feet. It is the same silt that forms and binds the boulder clay, but is entirely free from gravel or boulders. These have been named the white silt deposits. "They are generally fine and uniform in texture, and are usually well bedded in perfectly horizontal layers from ¼ inch to 4 inches in thickness," with occasional sandy seams and small pockets of coarse sand, formed locally, appearing in places.

By the continued application of large quantities of irrigation water upon the cultivated fields above, and upon the upper portions of what are now the slides, almost the entire surplus not absorbed by the plants or evaporated, sank down freely through the loose soil, sand and gravel; and while not as readily, yet with considerable ease, through the boulder clay, and reached the underlying silt. After some years this water saturated the argillaceous silt and converted it into the form of river mud of about the consistency of thick pea-soup. Long before the whole mass, or even

a very large part of it, reached a state of perfect saturation, the silt would lose its power of sustaining weight. In the two places here referred to, on account of the peculiar topographical and geological contour of the country, the water applied at the back was concentrated, comparatively speaking, into one channel of descent (in each place) to the body of silt below, and thence it penetrated in every direction. The process of saturation required many years to produce any results, for if a considerable quantity of the silt had become saturated to the point at which it would lose all cohesion, it would not move, on account of there being so great a distance to any point of outlet, together with the self-supporting power of the boulder clay in its confined position, which was nearly all absolutely dry over the slip; hence a large extent of the underlying silt became more or less saturated before it could find an outlet in any direction, even with a considerable weight upon it in its more or less semi-liquid state. Finally, when a large body of the silt had become saturated to such an extent that it could not sustain even its own weight, except in its confined position, and the limit of resistance, possibly in the form of an arch, of the boulder clay had been reached, the great mass of earth and boulders above—in the case of the south slide, estimated as weighing some 32,000,000 tons, and of the north slide approaching 100,000,000 tons—the whole mass dropped almost vertically, while the immense tracts of broken and mixed material seeking an outlet forced their lower sides out on the line of least resistance and found their way into the river. This action is distinctly shown by the almost vertical walls in the boulder clay along the outline of these two slides. While at their foot there is now a talus slope of crumbled material, these walls stand vertically to a height of between 50 feet and 200 feet, more clearly shown in the north slide, where the vertical cliffs of boulder clay, and in places of the silt itself, extend round the whole slide for a distance of over 1½ mile. It is also shown by the present position of large sections of the original surface of the highest bench, which broke off at the line of the back wall, and which now stand in the sunken mass at an angle of about 45°, with their former level surfaces tilted back away from the river. The back edge thus dropped first and lower than the portion some distance in front of it. In dropping and pushing out towards the river, the whole tract was broken into sections by great cracks, which still exist. The larger cracks run parallel with the river and at right-angles to the line of movement, while other and smaller cracks run in

every direction, cutting the whole into blocks of boulder clay and dry silt.

Both these larger slides, together with some others of the kind, occurred before the railway was built. Others have also occurred in entirely new places since that time. On the land above the south slide (and on most of the others also) irrigation has continued since the railway has been working, and this has kept up a continual movement of the south slide, with a number of others, towards the river. This movement is much more marked for 500 feet or 600 feet in the centre of the slide, where the water seems now to be concentrated. Thus the railway is being continually pushed out into the river. At times the road-bed has sunk 4 feet and has moved out twice that distance in a night, so that a constant rebuilding of the line has been necessary for the last 10 years. The movement is continuous, though it is greatest in the months of July, August and September. An extra force of section men, watchmen, construction trains, &c., are continually required on this section. At the south slide alone over £10,000 has been spent on such work. This section of 5 miles or 6 miles of slides has cost the Canadian Pacific Railway Company directly and indirectly £100,000, in keeping up a safe road-bed, and in other necessary expenses. At one point a train-load of tea was thrown into the river, and completely lost, by the sudden movement of a portion of the road-bed, caused by an extra amount of water being put upon an already saturated field. The most careful guard by extra watchmen is kept on this part of the road, and trains run over it at only 6 miles an hour. A few years ago, after the watchmen had passed over the line, and an east-bound train had also passed over it in safety, a west-bound train came suddenly upon a section of the line sunken out of sight. The train fell into the river and the engine-driver was killed. This also was caused by the excessive irrigation of a small field above the line.

The great north slide happened in October, 1881. Irrigation had been carried on above it for some years, and some time before the final catastrophe occurred, a reservoir 2 miles distant in the hills from which the irrigation water came, broke its dam, and most of the water liberated spread over the upper benches of this land, already well soaked. The whole tract of 150 acres sank vertically in one movement to a depth, at the back edge, of over 400 feet. The lower portion, about 2,000 feet wide, was forced entirely across the river, a distance of 800 feet to 1,000 feet; and coming against the steep bluff on the opposite side, it filled

the whole inner gorge of the valley, and formed a dam fully 160 feet high, completely stopping the flow of the river for several days, so that men walked dry-shod across the river-bed below the dam. The Thompson River carries in the autumn 15,000 cubic feet to 20,000 cubic feet of water per second. The dam formed a lake over 12 miles in length, which is roughly estimated to have contained 7,000 million cubic feet of water, Fig. 2, Plate 1. As soon as the water rose above this dam of loose broken material it was swept away, and caused a terrific flood in the valley below.

All the arable land above the north slide was carried down by the first break, and hence irrigation was stopped at that point. After some years the water drained out so completely that the movement practically ceased and the land became again stable. The railway crosses this slide 500 feet or 600 feet back from the river, and since the water has drained out, little trouble has been experienced, for the land has settled firm and dry. At the south slide, irrigation being maintained, there has been a continuous movement ever since the railway was built across it. The central portion has advanced toward the river about 800 feet since it first fell. As the material is forced forward the river washes it away, a new road-bed is built further back, and the line is moved inland to it. This new bed gradually sinks and moves forward, and the line must be continuously raised and moved in, to keep a safe passage across the broken and moving ground. Such work is in progress to a greater or less extent over the whole series of some 5 miles or 6 miles of slide. The expense and difficulty are so great that, to use the words of the general superintendent of the road, it has become "almost impossible to work the railway."

At Spence's Bridge, some miles down the river, a slide occurred from the same cause on the west side of the river. It crossed entirely over the stream and deposited a number of acres of land on the east side of a bench 25 feet above the river, between it and the railway, covering an Indian burying-ground.

At one time the tract of land on which the town of Ashcroft now stands began to move towards the river. The Dominion Government bought out the farmers who were irrigating above the town; the irrigation ceasing, the movement soon stopped, and the town has since remained in the position it then occupied.

Physical Geography.—The Province of British Columbia, extending from lat. 49° N. to lat. 60° N., forms the northern extension of the Rocky Mountain region of North America. The two principal

mountain systems are the Rocky Mountains proper and the Coast Ranges. These form the north-eastern and south-western boundaries of an interior section of the province. "Between these two limiting systems are found, on the side next to the Rocky Mountains, several less regular though often equally lofty mountain ranges, which may be collectively referred to under the name of the Gold Ranges, being west of the Selkirk Range, and between these and the inner margin of the Coast Ranges lies the region called the Interior Plateau." [1]

The Interior Plateau, across the southern part of British Columbia, is nearly 200 miles wide. It has an average width of about 100 miles, with a length from south-east to north-west of about 500 miles. The general level declines towards the north and west, having an average elevation in its southern portions of 4,500 feet, sinking as stated to the north-west to a much lower level, and having an average height above the sea of about 3,500 feet. Only in contrast to the lofty and rugged mountains which border it, can this interior region be properly called a plateau. "More carefully examined, it is found to consist, particularly in its southern part, of numerous blocks of plateau-like contour, separated by important depressions, and differing considerably in their actual elevations. But there is every reason to believe that, in the early Tertiary period, the area of the interior plateau had become reduced by prolonged denudation to the condition of the nearly uniform plain. . . . Though never absolutely flat, the surface of the country thus became an approximate plain or what is called a 'peneplane.' It appears further that the peneplane at this time formed has never since been entirely obliterated, although it has passed through several stages of elevation and depression, and has been subjected to more or less deformation due to earth-movements. At certain periods it has been an area of deposition of strata, and the theatre of great volcanic eruptions. At times the natural forces of waste have been engaged in reducing the superadded irregularities toward the old plain; but during the latter part of the Pliocene Tertiary period, with the country standing at an elevation higher relatively to the sea than at present, the greatest erosive changes, tending to the destruction of the ancient plateau, occurred. At this time the great valleys by which the interior plateau is now conspicuously trenched—those of the Fraser River, the Thompson

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[1] "Geological Survey of Canada," vol. vii. part B. Annual Report, G. M. Dawson, C.M.G., LL.D., F.R.S., Director.

River and their main tributaries—were cut."[1] Thus, considering its origin and former condition, the present appearance of this interior plateau, when seen from a sufficient elevation, is that of a number of high plateau areas, which run together everywhere in the distance, shutting out from view the great lower valleys; and while these areas differ considerably in elevation, they do not so differ materially as between adjacent parts. Even with the more marked irregularities on its west or south-western side, this interior section may be considered in general as a plateau, and particularly as a country peculiar to itself, not only as to its origin and partial present form; but also with reference to its general climatic characteristics, its vegetation, rainfall, &c.

Climatic Conditions.—Situated with its western border within 100 miles of the Pacific coast, where the rainfall at Vancouver attains 62 inches, and at other points even exceeds 150 inches per annum, the average rainfall of the larger part of the interior plateau is only 6 inches to 12 inches per annum. The Coast Ranges form an almost complete barrier between the Pacific and the inner country, so that the moisture-bearing winds from the ocean become desiccated before they reach the latter region. "A study of these conditions will show how it happens that the lower valleys and those nearest the Coast Ranges form the most arid part of the district, while the humidity of many of the higher parts of the plateau, particularly those situated to the eastward, is at the same time still considerable, enabling them to be the sources of perennial streams which may be employed in the irrigation of the lower and drier tracts." The climate of many parts of this section seems out of relation to the geographical position of this far-north country. It is largely governed by the close proximity of these mountain ranges. The difference of temperature during the year, and even during the day, is very great. In the valley of the Thompson River it ranges from 120° in the summer to, at times, 50° below zero in winter.

Larger portions of the higher hills and valleys are covered with dense forests, including among their trees the black pine (*Pinus Murrayana*), white spruce (*Picea Engelmanni*), Douglas fir (*Pseudotsuga Douglasii*), and balsam spruce (*Abies subalpina*). The mountains range between 8,000 feet and 9,000 feet in height. The timber limit is about 7,000 feet. Below this, for some distance, the hills and valleys are but sparsely wooded on account of the extreme depth and long duration of the winter snows.

[1] "Geological Survey of Canada." Annual Reports, vol. vii. part B.

Below the denser forests, the valleys are but partially covered with trees, for the opposite reason—the want of sufficient moisture; while the lower and larger valleys, up to an elevation of about 3,000 feet, are almost entirely devoid of trees on account of the extreme dryness of the climate. The lower valleys with their slopes and terraces only produce naturally a few shrubs and grasses, the most abundant being the bunch grass (*Agropyrum tenerum*).

Geological Formation.—The geological formation of the section within which the land-slides have occurred embraces the cretaceous formation of the Ashcroft area, and the triassic formation lying immediately south of that, with a small portion of the carboniferous formation lying still further south. In considering the real nature and causes of the slides, the solid geology does not have so important a bearing on the matter as the present position and condition of the superficial or drift deposits due to the glaciers, which now partially cover, and at one time largely covered, the interior country. In the case, however, of the two largest slides at the Black Cañon, which have already been described, the underlying rocks (at that point cretaceous) are important in establishing a correct estimate of these causes.

The Glacial Drift.—The most important and extensive deposits of drift are the boulder clay and the white silts. The former, which in many places resembles a partially cemented gravel, consists of a paste of hard sandy clay silt, with a large amount of sand or coarser silt; through it, in close proximity to one another, gravel, stone and boulders are found, from the finest pebbles up to boulders between 2 feet and 3 feet in diameter. Some are glacial, marked and polished, but the larger part are shaped by ordinary water action. The stones and boulders in places have come from one locality, and in others they are of varied origin. It is impossible to give the general thickness of this deposit, though it is evident that in some low portions, and in the valleys, it attains considerable thickness, and, on the other hand, that the higher parts of the districts were never covered with this deposit. The greater part of the boulder clay deposited in the larger valleys was removed at a later period by denudation. The white silts were deposited at a subsequent time. They reached an extreme elevation of 2,500 feet above the present sea-level, while the highest levels of separate deposits of these silts are found at other distinct levels, in different localities, down to 1,700 feet, showing possibly an uplifting of parts of the country during their depression. The extent of this silt deposit was

at first very great, but much of it has been removed, as was the case with the boulder clay, by denudation.

The western part of Canada was covered by the great Cordillean glacier,[1] which attained a maximum length of nearly 1,200 miles, and over the higher tracts of the interior plateau of British Columbia reached a general thickness of between 2,000 feet and 3,000 feet, while in the main river valleys (cut out during the Pliocene Tertiary period) it must have been 6,000 feet in thickness. During the maximum of this glacier, the whole region stood at a much higher elevation than at present. Eventually there came a subsidence of the mountain region, and a retreat of the Cordillean glacier. During the retreat of the great ice-sheet lakes were probably formed on its surface, which increased in size as the subsidence progressed, and after their final drainage, and the further retreat of the great glacier, the interior plateau was covered by gradually deepening waters which were connected with the ocean. It was during this retreat that the boulder clay of this section is supposed to have been formed. The next great change was a re-elevation of the whole territory and the forming of the higher terraces of British Columbia. During this elevation much, and in some parts all, of the boulder clay deposit was washed out of the larger river valleys, such as those of the Thompson and Fraser, as the rivers for a second time cut a channel for the waters draining from the lakes and glaciers, and pouring out into the ocean now below their level. Later, in consequence of this elevation, the country was again covered to a considerable extent by glaciers, though these were local in character. Then occurred a second subsidence, less than the first, but which lowered the level of the region about 2,500 feet below the present one. At this time, with glaciers of considerable size occupying the mountain valleys, the land remained nearly stationary for a long interval, and remarkable and important silt deposits, well bedded and of considerable thickness, were tranquilly laid down in different low tracts, scattered along the Cordillean region for a length of some 1,200 miles. These have been termed the white silts. The final retreat of the glaciers was not connected with subsidence, but was either during, or soon followed by, a general elevation of the region, and is supposed to have been chiefly due to a general amelioration of the climate, the cause of which does not seem clear. Following this elevation the present large rivers cut for a third time a channel for themselves, this time principally in the white

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[1] G. M. Dawson.

silts, which had been deposited in their gorges and over the remaining boulder clay. In some places the silt has been completely washed out of the original gorges, while in others it still covers the whole floor of the valley. In most places it remains only on the sides of the valleys, and stands in terraces along and far above the river. These terraces of silt, next to the large rivers, in places stand to a considerable height with only a thin soil above them. Others farther back are covered by a heavy deposit of re-arranged or secondary boulder clay, and again, still further up, are found large sections of silt over the original deposit of boulder clay, these in turn being covered by the secondary, re-arranged boulder clay.

Local Conditions.—The various actions during the glacial periods, as related above, are almost entirely responsible for the condition of that portion of the Thompson River valley in the neighbourhood of the Black Cañon. The great gorge cut during the Pliocene Tertiary was at first filled by the boulder clay. This is found at the elevation of nearly 2,000 feet above the present river, and is shown in cuts of the railway close to the water. When the river cut its channel through the boulder clay, large masses of this material were left on the east side of the river, both above and below the Black Cañon. The boulder clay here found is of two kinds. The first deposit as first laid down, and the secondary or re-arranged deposit as formed from the original by the action of the river at its various heights, and also by the submersion and re-elevation during the laying down of the white silts.

From a careful examination of this section it would seem that possibly the ancient pliocene river ran, when at its lowest levels, to the east of the present Black Cañon, and east of the two prominent points noted above, and that, when cutting its second channel through the boulder clay, the current was thrown to the west, cutting its way through the shattered shales west of the two higher and hard sandstone points, leaving a great mass of boulder clay to the east or back of them. This action of the river would form, both north and south of the Black Cañon, great bays washed out from the boulder clay. These bays were subsequently filled with silt, and the river, cutting its third channel through the silt, followed in a more direct line to and from the Black Cañon. These are the conditions found at these two points, great bays of white silt extending in the case of the south slide, 1,600 feet back from the river into the original mass of boulder clay, and covered by the loose gravel and secondary or re-arranged boulder clay. In the case of the north slide, this

bay of silt extends back nearly $\frac{3}{4}$ mile, while no silt, at low elevations, is found at all across the whole section of the valley at the point between them, that is, east of the Black Cañon tunnel. The silt deposit in these two bays accounts clearly for the peculiar form and action of these two great slides, and for the immense vertical drop in each case.

While the white silts were being deposited, there was much re-arrangement of the boulder clay. At two points, one on the south side of the north slide, and the other on an exposed section of Nelson's Creek, are found deposits of silt on the original boulder clay of the higher benches, and entirely separated from the larger masses of silt below, and also covered to a considerable depth with the re-arranged boulder clay during the latest elevation of the territory.

Causes of the Slides.

I. *Natural Precipitation upon the Lands in and around the Slides themselves.*—The natural precipitation upon these lands would not exceed 6 inches per annum, and could have no effect upon the clay or silt lying between 100 feet and 400 feet below the surface of the higher benches. Even thousands of years of such precipitation could not reach the underlying stratum of silt. On a nearly level plain, a few miles north-west of the city of Denver, in the State of Colorado, where the surface drainage was not nearly so perfect as on the benches of the Thompson River, and where the precipitation is much greater than at that point, in sinking a shaft through fine sandy soil for the purpose of opening up a coal mine, it was found that for some 50 feet down to the rock the soil was absolutely dry and flew into dust and floated in the air when struck with a pick.

Natural Surface Drainage from the Watershed above the Land.—Barns's Creek and Nelson's Creek, together with the depression between them in which lie the natural lake and artificial reservoir, designated in Fig. 4, Plate 1, Barnes Lake, cut the tracts off completely from the mountain region to the east. On the slopes above and immediately east of the north branch of Nelson's Creek springs show upon the surface above a ledge of bed rock running north and south near to the surface—and at some points exposed—along the ridge next east of the creek. No such springs or any evidence of drainage water show to the west of this north branch of Nelson's Creek. This north

branch, which is cut deep into the gravel and rock, and also a smaller drainage system which abuts against and runs directly north from the source of this same north branch of Nelson's Creek, are, even in the driest season, as continual running streams, in places on clean rock. These natural drainage systems carry off all surface water from the mountain water-shed, and also any that may flow through the soil from the springs above, and being thus cut off it would in no way affect the lands lying below and to the west of these drainage channels.

Natural Drainage by Subterranean Streams.—(Fig. 4, Plate 1.) "This (Ashcroft) area is about 4 miles in average width, with a length of about 11 miles, and for the greater portion of this length the Thompson River follows its axial line. . . . No fossils have been found in any part of this area, but its lithological identity with the cretaceous formation of adjacent parts of the Fraser valley is sufficient to fix its cretaceous age. The rocks consist of sandstones, conglomerates, and dark shales, the shales here apparently predominating in the upper part of the series, and occupying in the main the central part of the area, while the sandstones and conglomerates are more abundant and characteristic in the lower parts. . . . The sandstones are usually greenish or greenish grey in colour, being largely composed of debris of the underlying diabases and felspathic rocks, and seldom or never purely siliceous. . . . The shales are blackish, and their sombre outcrop along the Thompson has given its name to the Black Cañon. . . . The rocks are nearly everywhere much disturbed and crushed, and no satisfactory general section has been obtained of them. Nearly all of the observed dips are to the westward, but as a rule those on the eastern side of the middle line of the area are comparatively low, ranging from 10° to 40°, while those on the western side are often at angles of 60° and from that to vertical. It is probable that the structure of the area as a whole is that of a syncline, of which the western limb has been more or less completely overturned by pressure acting from the west."[1] One of these minor folds is the black shale ridge through which the Thompson River has cut its way and has formed the Black Cañon. This fold here lies on the eastern limb of the general syncline, its trend being north and south, and having its anticlinal axis on the east side of the river and just east of the railroad tunnel and cutting. This shale ridge is somewhat over 1 mile in length

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[1] "Geological Survey of Canada," Annual Report, part B, vol. vii. pp. 154 and 155.

where the river is cut through it. Its abrupt termination is shown at both ends on the west side of the cañon where its wall terminates abruptly in the boulder-clay deposit, and for that distance and to the height of 100 feet and more is composed entirely of black shale, dipping abruptly to the west, and at an angle much greater than the general dip of the eastern limb of the main syncline.

On the east side of the river, and forming the eastern side or wall of this little cañon are two lesser folds of this one "minor fold." The anticlinal axis of one is at the point through which the tunnel runs and the other at the centre of the open cutting just north of the tunnel. The direction of these axes are nearly east and west. The hard greenish sandstone rock under the black shale is raised and exposed in the tunnel, and cut some 50 feet above the railway line, and in both cases it terminates abruptly close to the eastern wall of the cañon. On the top of these points is a stratum, 20 feet to 30 feet thick, of the black shale (on the wall of the cañon the shale shows over 100 feet thick), dipping over the points very abruptly into the river, and folding down north and south round these points, with also some dips showing as inclined to the east away from the river.

These facts and the additional evidence that immediately east of the tunnel (Fig. 3, Plate 1) is the break of the south slide and east of the open cutting is the break of the north slide, and several hundred feet below the top level of these two elevated points no rock appears, but simply a mass of boulder clay and silt, led the Author to conclude that it is most likely that the ancient pliocene river ran, when at its lowest levels, to the east of the present Black Cañon, and east of the two points here described, and that when cutting its second channel through the boulder clay, the current was thrown to the west, cutting its way through the shattered shales, and leaving such a mass of boulder clay as is formed east of the cañon. This ancient channel was but a short distance east of the cañon, for on this cross-section east of the two slides, about 1 mile from the river, the rocks are exposed in place and dipping again to the west.

The fact that the rocks are nearly everywhere much disturbed and crushed; the numerous indications of faulting; the volcanic nature of many parts of the section, these volcanic rocks showing both north and south of this point; the minor and lesser folds in the immediate neighbourhood, with a possible older and lower channel of the river, in which the great masses of silt and boulder

clay which compose these two slides were deposited, and from which channel there would be an outlet lower down into the present river, would seem to entirely set aside any possibility of underground streams upon or in the seams of the rock reaching the silt and causing the slides in the manner in which they occurred. Leaving out of consideration any possible older or lower eastern channel, it cannot be assumed that at the two particular places where the slides occur the underlying rock strata are uniformly inclined and unbroken, and that over them or through their seams the water reached the silts and caused the slides; for it must be at once asked why this action did not occur centuries ago.

Effect of Surface-Streams Running by the Land.—This effect is intimately connected with the questions coming under the fifth and last division of the subject, and can only be partially treated as a separate item. Two streams — Nelson's Creek and the Thompson River—run by, and come in partial contact with, the south slide. In the case of the former, the present stream runs in a deep gulch, partly (the north branch) in a trench cut down through the boulder clay, where the banks stand in nearly vertical walls, and further down the stream it flows on clean bedrock, and still lower over a bed formed on the debris of the boulder clay and silt. Even in the driest season this is a continual running stream fed by springs. At its upper end on the north branch, these springs come in from the east side, while the west side is absolutely dry. In its lower section they come in from both sides, but more especially from the irrigated land, which is much higher than the bed of the stream, as there is a section of unbroken land lying between Nelson's Creek and the slide itself, the only way this stream could affect, or could have been the cause, or partial cause of the slide, would be by soaking through this mass and into the underlying silt. By two careful measurements of the water flowing in this stream, made in November, 1896, one being at a little fall on bedrock above the slide, and the other at the railway bridge, just before the creek enters the rivers, it was shown that there was 18·6 per cent. more water running in the stream at the lower point of measurement than at the upper, these points being about 1 mile apart; and further, that 90 per cent. of this increase came from the side next to the slide and from under the present irrigated fields—a result entirely opposite from what would occur if this stream were supplying the water to flow into the slide and thus keeping up the present action. It was also shown that at least 95 per cent.

of the water running into Nelson's Creek during that dry season was irrigation water from the upper fields, and that the surplus water applied upon the fields and orchards to the east of the north branch did not to any extent sweep down under the creek, but came out into the stream and was thus carried to the river.

The Thompson River flows along and against the foot or toe of all the slides, and in their present condition, that of a broken and moving mass, gradually pushing their way into the river, has a more or less marked effect upon them. At the south slide, especially during high water, the action of the river is most marked. The condition of the material, as described above, cut in every direction by huge cracks and being forced into the stream in detached and broken blocks of boulder clay and dry silt, invites the water to enter the cracks and seams. Thus getting in behind and around these blocks it readily melts the argillaceous silt, and the rapid current washes the material away. The river, even during high water, carries away only that portion that is delivered to it in this crushed condition by the force of the continually moving slide. It would be impossible, within any reasonable limit, to place any protection from the river upon the toe of this slide. The force from the millions of tons above is practically irresistible.

That the river, running as it does at the foot of these slides, has in no degree been the original cause of any one of them is clearly shown by the fact that there are hundreds of places close by and between the several slides, and at other points, where the banks of the river are walls of boulder clay and even of the clean unprotected silt, which stand in almost, and in some cases in actual, vertical cliffs between 10 feet and 100 feet in height, against which the river has run for many centuries without any material effect, and in no case causing slides where no irrigation has been done above them (in places small cave-downs have occurred); while, on the other hand, in every instance along the Thompson (and in other sections also) where irrigation has been practised above such a formation of boulder clay and silt, after a few years of application of the water more or less great land-slides have occurred.

Artificial Irrigation of the Lands Upon and Above the Slides.—By the testimony of Indians who had lived in the country all their lives and that of some of the original white settlers, no slides had ever occurred at any point along the Thompson River before the white men began to irrigate the land, although one or two small cave-downs existed before that time. In every instance noted, these

slides occurred between 3 years and 6 years after irrigation began at each point. In the case of the largest one, the great north slide, the final catastrophe was hastened by the bursting of the reservoir. A very large amount of water was necessary for raising crops, on account of the sandy nature of the soil and the nature of the subsoil. The topography of the several benches assisted materially toward the final result. Each field being in the form of a shallow basin, around which the irrigation ditches were built, little of the surplus water was drained off, hence the greater part of that not taken up by the plants or evaporation, ran towards the centre of the field and soaked down in one channel.

As to the action of the water upon the peculiar masses of silt which at present underlie the benches and terraces along the Thompson River, a number of curious facts were noted in and around the south slide, which at first seemed most difficult to explain. The silt or imperfect clay, which lies in masses between 200 feet and 1,000 feet in thickness, is generally fine and of uniform texture, and usually well bedded in horizontal layers of from $\frac{1}{4}$ inch to 3 inches or 4 inches thick. In its natural state it is hard and dry, like a soft sandstone, and, when held between the fingers and struck with a light hammer, rings like stone. A large piece of this silt, however, placed in a basin of water dissolves after a few minutes and falls down, not in a lump as clay, but it mingles with the water, forming a semi-fluid mass like thick pea-soup. The same soft mixture was observed oozing out at many points along the foot of the slide, forced out by pressure from above; so the question arose, how it was that this silt stood in vertical walls between 10 feet and 100 feet in height along the Thompson River and Nelson Creek, with the waters of these streams running along and against their base, and at high water some distance up them, and yet they had stood for ages, and were but little injured, except by slight atmospheric disintegration?

The silt is formed of three parts—silica in the form of coarse and fine sand, and alumina in two forms, first disintegrated felspar, simply mechanically separated into grains, both coarse and fine also in the form of sand, and constituting a large part of the mass, and second, decomposed felspar or plastic clay. Under the action of running water, the sand, both the silica and the disintegrated felspar, is washed out, while the decomposed felspar is precipitated, and forms a coating of true plastic clay upon the mass, which soon becomes impervious to the water and is practically indestructible, thus protecting the underlying silt from further action of the

water. The result of a chemical examination of the material will be found in an Appendix. Mr. Warsap, the analyst, also suggests the chemical action and assistance of the carbonic acid of the atmosphere and ammonia, if present in the clay and the lime, in forming this impervious coating. The mechanical action of separation and precipitation noted above accounts for all the peculiar phenomena observed at every point in and around the slides.

The great quantity of irrigation water soaked downwards into the mass of silt. It would absorb 53 per cent. of water without changing its form, yet with only about 35 per cent. it would be incapable of sustaining any great weight except in its confined position. After the final breakdown, and its release into the river with the continual application of water, and still being under pressure, this semi-liquid silt, containing all its original constituents, is forced out at the foot of the slide in great quantities. If a man steps on this ooze he is liable to sink into it, while within only a few feet of such a spot lay, when examined by the Author, a large block of the same silt which had fallen over into the river in a dry state, and over which the last season's high water had run; it stood up 3 feet or 4 feet above the level of the river beach, and the Author walked and jumped upon it without making any impression. Breaking off a piece of this block, it was found that, less than 1 inch under the surface, the silt was in its original form, and easily dissolved in water. In the river, under low water, were also observed great masses of this silt which had fallen over into the river in blocks, over the surface of which the river had run for years without carrying them away. On the other hand, the backwater in an eddy soaking through the cracks and getting behind and around other blocks completely dissolved them, and the river carried them away.

The bed of the lower section of Nelson's Creek, a rapid stream, is formed of this precipitated plastic clay, which prevents any water soaking out of it into the slide. But more noted than these instances is the fact that, on the walls of the gorges, the Thompson River and Nelson's Creek, which in many places are composed of this same silt, is found the same coating of plastic clay and lime—an imperfect cement—formed by the action of the running water. Thus these walls have stood almost vertically (in one place 100 feet high) for ages, withstanding almost entirely the cutting effect of the highest freshets. It is true that these banks of silt gradually disintegrate by atmospheric action upon them, and in the dry season the scale of plastic clay becomes

baked and drops off; but as soon as the stream rises by its assistance, Nature immediately erects a new bulwark against its ravages.

There is no way of preventing the continual disastrous effects of these land-slides upon the railway except by cutting off the irrigation water above. This has been and can be made effectual. The water so easily absorbed as easily drains out, and the mass after a time again becomes firm and solid.

The Paper is accompanied by three tracings, from which Plate 1 has been prepared.

APPENDIX.

Vancouver, B.C., Nov. 14th, 1896.

Mr. Robert B. Stanton, M.A

Dear Sir—The clay, or silt, you handed me for examination absorbs 53·5 per cent. (of its volume) of water without losing its form, and, after absorbing 78·5 per cent., it frets down and mingles with the water.

I have compared it with clay from Warnock, B.C., which takes 49 per cent. and 70·5 per cent. When the clay, or silt, you handed me has absorbed 78·5 per cent. of water, it seems to mingle with the water, whereas the Warnock clay drops into a square heap and remains there. The following analyses of this and other clays are given for comparison.

Yours truly,
H. J. Warsap,
Chemist.

Analyses of Silt and Clays.

—	Silt from South Slide, Black Cañon.	White China Clay or Kaolin.	Warnock, B.C., Blue Clay.	Average English Blue Clay.
Silica (S_2O_2)	26·75	46·8	60·05	63·35
Alumina (AL_2O_3), and Iron (Fe_2O_3)	56·60	37·7	31·08	18·50
Total Sulphur (SO_3)	6·8	..	1·02	4·32
Lime (CaO)	3·24	..	6·25	6·60
Water loss	6·61	15·5	1·60	7·23

[Discussion.

Discussion.

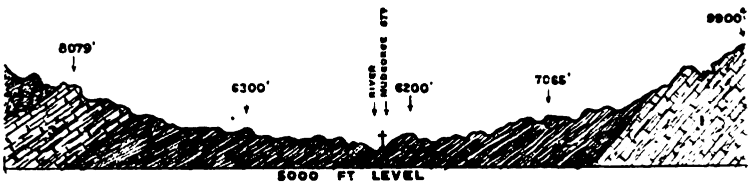
Sir J. WOLFE BARRY, K.C.B., President, was sure the members would all regret that the Author was not present to further elucidate his interesting description of the careful observations which had led him to important deductions in connection with the great landslides in British Columbia. The slides certainly were on that immense American scale to which engineers were not unaccustomed when hearing of what took place in that great continent. The Paper was an interesting one to engineers, as many of them might, on a small scale, have to deal with disasters somewhat similar to those to which the Canadian Pacific Railway had been exposed. No one could envy the engineer in charge of that length of the railway; but it was very satisfactory to know that by the careful observations of the Author, the cause of the slides seemed to have been tracked by his scientific mode of research. He was sure he was only speaking the sentiments of all present in proposing a hearty vote of thanks to the Author for his interesting contribution to the Proceedings. Sir J. Wolfe Barry.

Mr. G. R. JEBB thought it would add to the interest and clearness of the Paper if cross-sections could be given, one, for example, across the valley and across the north slide, showing the relative levels of the river, the railway, and the country above; also showing the thickness of the boulder-clay and of the various strata forming the sides of the valley. Mr. Jebb.

Mr. HORACE BELL remarked that the Paper was essentially a geological one, and it indicated clearly the necessity of attention to the geological features of any ground upon which works were proposed to be carried out. The cause of these great slips and the remedy for them appeared to be clear enough. The cause was apparently constant irrigation, and the remedy was that of ceasing it. It would no doubt have appeared to the Author that the remedy would perhaps be worse than the disease, as it would end in stopping the irrigation, and reducing the population and the traffic of the Canadian Pacific Railway. The great slides that had taken place on that railway were paralleled in some measure by the enormous slides with which he had had to deal in the Beluchistan frontier of British India. There they were due not to irrigation but to peculiar geological conditions. The line he Mr. Bell.

Mr. Bell. referred to connected the Indus Valley with the great military station at Quetta on the Beluchistan frontier; and at an elevation of 6,000 feet above the sea there was a valley which had rightly been called "Mud Gorge," consisting almost entirely of disintegrated shales overlying the lower nummulitic limestone, as shown in *Fig. 5*. The railway, which, perhaps, had been somewhat hastily located over the ground, had proved to be, both at this point and at others, a frequent source of trouble and anxiety to the Government of India. It was a connection between the Port of Kurrachee and the Afghan frontier, and any defect in it could hardly be contemplated with satisfaction either by the Government or by the public. The slides were mainly due to the fact that the shales were permeated by beds of gypsum and anhydrites, which, subject to subaqueous disintegration, forced the whole body of the shales from the upper hills down to the river, which drained the valley, and the result had been that,

Fig. 5.



Scale 1 inch = 1¼ mile.

1. Nummulitic limestone; 2. Middle Eocene, black shale and bund; 3. Upper nummulitic limestone; 4. Pliocene sandstones.

CROSS-SECTION THROUGH THE "MUD GORGE."

for over 6 miles of line, there had been constant and gigantic movements extending for a mile or more above the railway towards the hills, which were about 10,000 feet above sea-level, thus forcing the railway outwards towards the river. The treacherous nature of such ground was well known to engineers, one of the most prominent cases being that of the tunnel near Heilbronn in Wurtemburg, which had given great trouble many years ago, and resulted in a completely new line being made. The engineers had tried their best to cope with the difficulty; they spent in their zeal between £50,000 and £100,000 in trying to make the railway stable, but they failed, as might have been expected. In 1893, however, the Government of India appointed a small committee, of which he was a member, to determine whether those

operations should be continued, or whether each movement should be dealt with as it occurred. The committee carefully investigated the whole matter on the ground, and after considering the many heroic remedies proposed, came to the conclusion, with which probably the Institution would agree, that there was nothing to be done; that the best course was to take each slip or movement as it occurred, slewing over the line, and working with any gradients, or curve up to 300 feet radius, and pushing the traffic through as well as possible. In addition to this, the drainage of the slopes, in order to remove the water from the grounds quickly, was adopted, and since that time there had been comparatively little difficulty. The case, of course, totally differed from that which the Author had described. The one case was entirely a question of water, the other was a case of chemistry and water; but the moral of both was that, before investing large sums of money in public works, an endeavour should be made to test, as far as possible, the geological and chemical conditions of the ground to be dealt with. Mr. Bell.

Mr. W. R. Galbraith thought the Paper set forth the disease and the remedy. The disease was a large amount of ground moving probably on some stable bed inclined towards the river. In regard to the northern and more serious slip, the Author had said, that directly the irrigation—the supply of water poured in—ceased, the slip was arrested; and he could not see why the same remedy was not applied to the southern slip. It was thought that the purchase of the property now being irrigated would probably involve a large expenditure; but if the northern slip was 155 acres, the land irrigated between the two slips, the southern portion of that which seemed to be causing mischief on the southern slip, could not be much more than 200 acres; and it therefore appeared that the Canadian Pacific Company might long ago, instead of spending £100,000 in continual alterations of the line, have bought the irrigated land and stopped the water. In the case of a railway slip in England the first remedy would be to cut a drain round the back of the slip to take the water off, and the second remedy would be to make two or three drains so as to drain off the water below. The fact that the mere cutting off of the water behind had been effectual in curing the larger and more dangerous slip, seemed to indicate that the same plan ought at once to have been adopted with regard to the southern slip. He did not understand why that had not been tried long ago. If this were the slip of a railway slope a large bank of stone would be erected at the bottom of the dam, Mr. Galbraith.

Mr. Galbraith. forming a heavy drystone wall to retain the slope. In the present case this was out of the question, and the only remedy was to drain the slip and stop the water. If that did not cure it he should drive a tunnel through the slip at right angles to the river and draw the water off. He thought that would be much cheaper and better than continually watching and moving the railway, which must be dangerous. A great amount of silt below became impregnated with water, and the heavy mass resting upon it drove the silt into the river, forming a cavity, then the ground settled and broke away into a great number of crevices, causing the railway to be exceedingly dangerous. He thought there was a very simple remedy which might be tried at no great expense—stopping the irrigation in the lower slip, as had been done in the upper. That was what the Paper really seemed to imply; it was a very simple remedy, the amount of ground to be dealt with not being great. If that were effectual on the southern slip the company would be saved considerable danger in working the traffic, and a large amount of money in continual repairs and alterations of the railway.

Mr. Hill. Mr. G. H. Hill had had considerable experience in connection with works constructed for waterworks purposes in different valleys where such slips had taken place. In the case of the Manchester Waterworks there had been, 45 years ago, a very large slip, over which, in the Parliamentary plans, the water-courses were intended to pass. But when the ground came to be examined thoroughly, there was some doubt whether the water-courses could be carried across the slip (the area of which was double that mentioned in the Paper), and Mr. Bateman, the engineer, advised the Corporation to call in the assistance of Mr. Robert Stephenson and Mr. Brunel. Those gentlemen examined the ground, spending the day on the spot, and they came to the conclusion that the proper way to deal with the slip, which measured about ½ mile across, would be to drive a tunnel underneath it, and then to drive headings in all directions where the water was to be intercepted. The tunnel had been driven, and a great number of adits were put into the hillside from the tunnel; all the water was extracted from the slip, and it became absolutely stable. The water-course was then carried across the slip, conveying about 600 million gallons a day in flood times, and no trouble had since been experienced. It appeared from Plate 1 that, in making the railway up the valley, the cutting away of the old land-slips might have affected the balance, which never had been stable before the railway was made, and that changing of the balance of the

material would probably start the slip again in motion. He had himself seen such cases. A slip had occurred in the Ashton waterworks of 36 acres; the contractors, in making the embankment, ran a wagon road at the foot of the hill for a distance of 200 yards or 300 yards, and they started 36 acres of land in motion. In the same way, in the making of the railway some of the old slips might have been set in motion. The course he should have adopted would be to begin near the river-level and drive a heading right in, making adits in all directions and tapping the water. If the lower part was stable it would retain the upper part in its position; but there could be no better way of creating a slip than to bring water upon it for irrigation purposes. That would sink through and, coming down to the rock or shale, a movement would take place upon the surface which would be greased by the admission of water. The only way to stop slips was to get the water out; the mere fact of making drains round it would not, he thought, be effectual. Mr. Hill.

Mr. H. Osburn considered that if cross-sections of the Thompson river valley had been given, as well as a description of the levels of the land on each side of it, the cause of the slips could be better judged. He had spent two or three days near Ashcroft, at the back of the country where the slips seemed to have commenced. He thought slips had constantly been in progress in that valley, and he was surprised to find that the irrigation above had been given as the cause. One could ride for the whole of a day in that district and only pass one or two ranches, the greater part of the country was entirely uninhabited. He had ridden on a mule up the mountain side, and was able to form an opinion of the country; irrigation was only carried on in a very few places, and it seemed to him very strange that the slides should occur in those places. There were natural streams and reservoirs, and no doubt they sometimes broke bounds, and, rushing down, caused the slips. The whole valley showed, however, that these slides were not unnatural; they were going on constantly. Mr. Osburn.

Mr. L. F. Vernon-Harcourt had had the opportunity in August and September, 1897, of going to Vancouver by the Canadian Pacific Railway, and though, unfortunately, he did not see the exact places described in the Paper, because the railway train always passed them at night, going and returning, he had seen places alongside the Fraser River, of which the Thompson River was a tributary, where they had been putting the railway further back from the river. The former course of the railway could still be seen; and there had, no doubt, been slips to a certain extent in Mr. Vernon-Harcourt.

Mr. Vernon-Harcourt. that part. If the slides described were really caused by irrigation, he agreed with Mr. Osburn in thinking that in a place like Canada, where there were immense tracts of country perfectly unoccupied in more favourably situated localities, such as the land offered for sale in Manitoba at about 1*s.* 6*d.* per acre, and far more fertile than the places described in the Paper, it would be much cheaper to buy out the people who had that small area of land and stop the irrigation than to continue contending with the slides. There were other places on the Canadian Pacific Railway where smaller slips had occurred. He had noticed one especially in the Kicking-horse River Valley, on the western slope of the Rockies, where the sharpest curve upon the Canadian Pacific Railway had to be introduced, where a tunnel had formerly been constructed for the railway through a projecting spur, which, on account of the slides, had to be given up. Apparently some trouble had occurred from slides during its construction; and it was now abandoned, and a sharp curve had been substituted for the railway, running round the spur. That curve was only 262 feet radius. Mr. Cuningham, in his account of that portion of the Canadian Pacific Railway, stated that the spur through which this tunnel had been formed consisted of blue clay interspersed with layers of sand, with an overlying mass of boulder drift.[1] The action of water, he thought, in that treacherous formation had caused the slip. They had, accordingly, been obliged to put in round that spur the sharpest curve on the line of 262 feet radius, the next sharpest being 573 feet radius, or what was known in America as a 10-degree curve. Round that curve the railway went without an elevation of the outer rail, because the curve being so sharp the projecting roofs of the cars, if the rail were super-elevated, would touch one another. A guard-rail had been put in, but it was curious that on most of the other sharp curves a guard-rail was not used. They had put one in, in that case, he supposed, because they were not able to elevate the outer rail. The train went round at a very slow pace, and in that way, with the help of the bogies on which the cars ran, was kept on the line. There were also other places on the line besides the Fraser River where there had evidently been some slips, for example, on the ascending slope of the Selkirks going west, before getting to Rogers' Pass, where they were trying to consolidate some of the fallen portion of a large slip, in a steep ravine above the railway, by directing a stream of water upon it, as in some parts they had consolidated embankments upon the

[1] Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 108.

Mr. Vernon-Harcourt.

same principle. The great difficulty with regard to the Canadian Pacific Railway was that, on account of its not being able to follow a regular definite river valley like that of the Columbia River, it had to go through very narrow cañons across the Selkirks and the Gold Range, and therefore there was very little choice of route. Along the Fraser River, moreover, the train ran for some distance in a narrow gorge; and whilst fairly close to the river bank a high cliff rose directly above the railway on the far side. All the way down from the Selkirks, and most of the way from the Rockies, there was very little possibility of changing much of the route of the line. The Columbia River flowed in a very peculiar course, so that although the railway followed along the wide Columbia River Valley for a short distance on leaving the Rocky Mountains, it had to leave the river again soon because it went so far north in order to get round the Selkirks; and the railway crossed the Selkirks by Rogers' Pass. The railway then descended again to the Columbia River Valley where the river flowed south in the opposite direction parallel to itself on the other side of the Selkirks; and as the Columbia River continued its southerly course down to the United States, the railway had to cross it again at Revelstoke, and pass westwards across the Gold Range through the Eagle Pass. There again, though there was but little elevation, the pass was narrow; whilst down the western slope of the Selkirks there was the contracted Albert Cañon, so that there was very little opportunity of modifying the route of the line. How far it would have been possible to have avoided the slides, if the geology of the district had been thoroughly known, by carrying the railway on the other side of the Thompson River he could not say; but it was quite possible that it might have been done, because a little below the confluence of the Thompson River and the Fraser River was crossed by the railway, and the line kept along the western and the northern side of the Fraser River, from thence to Vancouver, and he thought it just possible that though they could not materially change the route of the line, they might have gone on the opposite side of the Thompson River at the site of the slides. The best course now appeared to be to stop the influx of water by buying out the proprietors of the ranches above, and arresting the irrigation where injurious.

Mr. Benedict.

Mr. E. Benedict found it difficult to locate the same place on the different maps given in Plate 1. If the degrees of latitude and longitude were given this would be facilitated. Most of the speakers appeared to have overlooked the last paragraph in the Paper; the Author did not mean to stop all the irrigation, but

Mr. Benedict. to intercept the water just before it reached the railway, thereby making the toe of the slip solid, so that the top would not be inclined to move. It appeared to be a very exceptional place, such as was not likely to be found anywhere else, and the causes of the movement were clearly set forth by the Author. The water in the case described was carried on to the land by small rudely-constructed ditches built almost entirely by the farmers, so that they were not watertight. That was the first step towards the slip. It was seen at Ashcroft that by stopping the irrigation the movement was stopped. It was also said that nearly all the dips were to the westward, and this also tended to start the slips. He thought it was of very little use to discuss the slips that were so exceptional and unlikely to occur elsewhere; besides, the Author himself had pointed out the remedy, and he thought there was no more to be said.

Colonel Pennycuick. Colonel Pennycuick, R.E., was, like other speakers, in some difficulty on account of the absence of cross-sections. He imagined there was a deep bluff immediately above the river, with a table-land on the top. In that way the water was distributed over the surface, trying to get down to the river just under the boulder clay, and got to the sand below. In irrigation works in Southern India much the same state of things was often experienced, though on a much smaller scale, and the remedy in every case had been simply drainage. In other words, the water had to be taken out as soon as it got in. In many cases of violent slipping of the rear slopes of embankments, the remedy had been to drive drains into the bank as far as it was safe to go, and to let the water run out freely without passing through the earth. He could not help thinking that something of the same sort was possible in the present case, but without sections it was impossible to say what the proper remedy should be. In the concluding paragraph the Author had stated exactly the remedy he proposed—not to stop irrigation, but to cut off the water, to take it by properly-constructed watertight drains down into the river instead of allowing it to get under the surface of the soil. He knew of one instance, in one of the large tanks of the Madras Presidency, which had an embankment about 40 feet high, where the rear slope slipped so badly that it forced a road which ran along the foot of it 30 feet out of its proper direction, pushing the whole road into the rice-field below. That had been cured by the simple process he described. They cut away the rear slope as far as they dared and drove drains in, running transversely to the bank, and connected by longitudinal drains, which collected all the water that leaked in

and carried it out harmlessly. That was twenty-five years ago, and he believed the bank was now as safe as could be desired. Colonel Pennycuick.

Sir JOHN WOLFE BARRY, President, thought some idea of the cross-section could be formed from a passage of the letter-press in the Paper, which stated that the bluff, where the break-off took place, farthest from the railway appeared to have been about 400 feet in depth, so that it might be imagined a considerable cliff had there been formed to begin with. Sir John Wolfe Barry.

Correspondence.

Mr. JAMES R. BELL had had occasion to study the problem dealt with by the Author on a no less gigantic scale at the Mud-Gorge slips in Beluchistan, where in earlygeologic times a dam of solid limestone rock some 2,000 feet high must have upheld a lake of mud some 10 miles long and 3 miles or 4 miles wide. How far the sides of that lake squeezed together and pressed up the centre of the clay lake hundreds of feet above the dam, or in what other way the clays were upheaved above their original level, their crests on either side of the valley were now far higher than that of the Chappar Mountain which formed the dam. The dam had not failed as a whole, but it had seemingly had a tunnel bored through it by (probably thermal) springs, and the roof of the tunnel falling in while the bed scoured deeper and deeper, the mountain was now cleft in twain by the famous Chappar rift, one of the most remarkable cañons yet encountered by any railway. The present Mud-Gorge Valley had been formed in the clay by the action of a small stream, which had carried away the mud from its bed through the rift. The bed of this stream was alternately raised locally when squeezed up by slips and lowered by cataract-like retrogression of the river-levels. Here and there narrow strips of level "bottom" occurred beside the river, but for the most part its banks conjugated every tense and mood of the verb "to slip" except the past pluperfect. The valley was now about 3,000 feet deep and about 3 miles wide; and beyond the fact that in a recent sequence of droughty years there had been less trouble than in average rainfall, there was no reliable indication of amelioration. The case might admit of remedies, but such skill as the Government of India had been able to bring to bear on this crux had not yet offered any more promising remedy than to watch the place, and put in deviations of the line as stoppages threatened. It turned Mr. Bell.

Mr. Bell. out (now that the country was getting settled beyond the valleys occupied by the railway) that this part of the Suleiman plateaux teemed with rifts even grander than the Chappar, and doubtless with mud-gorges of corresponding mobility. It was especially noteworthy that both in the Mud-Gorge Valley and in that under consideration the clays contain a considerable proportion of gypsum in crystals, liable to expand when slaked by water, and thus to create "slip-planes" analogous to the greased launching-ways used by ship-builders. Although the railway through the Chappar rift offered grades of 1 in 40, the Government of India, in view of the vast military and political importance of a railway to Quetta, had recently determined to build at great cost an alternative line with ruling gradients of 1 in 25 in another valley, whose paramount advantage consists in its having well-nigh completed its processes of denudation in their more active phases. He alluded to the Mushkaf-Bolan Railway, recently described by Mr. James Ramsay.[1] Compared with Indian experience in a hostile and newly-acquired territory, Mr. Bell was very favourably impressed by the thoroughness of the geological diagnosis, which the Author quoted from Professor G. M. Dawson. He saw little need for the hypothesis that the ancient pliocene river scoured out the beds of the lakes of white silt that now underlay the boulder clay, but that was a mere detail. The Author appeared to consider that it was necessary for water to entirely saturate vast masses of such silts before any motion would occur. On the strength of Mud-Gorge experience, any such extent of hydration as that indicated on p. 4, where the catastrophe was finally attributed to a large body of the silt being saturated till it could not support itself, far less the superposed clay which spanned it like a bridge, seemed quite unnecessary. It was quite clear that at Mud-Gorge the slip did not occur because more or less saturated and semi-liquid silt had found an outlet, but, on the contrary, slurry only found an outlet in consequence of a slip being established. He was far from contesting, in offering this experience, the practical view that water was the proximate cause of all slips, and that buying out the irrigation might effect a material amelioration of the Canadian Pacific Company's difficulties. Indeed, he was only at a loss to conceive the arguments that had seemingly prevailed for years against this treatment and until £100,000 had been spent in remedies of an imperfectly successful class in the teeth of a neighbouring example. Stopping the irrigation would certainly check the

[1] Minutes of Proceedings Inst. C.E., vol. cxxviii. p. 232.

slipping of the valley flank, whether it checked those slips that immediately affected the line or others more remote in the first instance. Mr. Bell.

Mr. H. J. Cambie[1] observed that on p. 5 the Author stated that "at times the road-bed has sunk 4 feet, and has moved out twice that distance in a night." His experience as engineer of the western division of the Canadian Pacific Railway led him to the conclusion that this statement would convey an erroneous impression of the safety of the railway. A movement had occurred in 1894, but it was not nearly so rapid as that described, and no such motion had occurred before or since that time. It was also stated by the Author that "this section of 5 miles or 6 miles . . . has cost the Canadian Pacific Railway £100,000." Such an assertion was not warranted by the evidence, and it was doubtful in his mind if the cost had reached one-fifth of that sum. Again, it was stated that "at one point a train-load of tea was . . . completely lost, by . . . an extra amount of water being put on an already saturated field." No tea-train had been wrecked within 100 miles of the slides referred to, or anywhere on account of irrigation. On the same page the Author stated that "after the watchmen had passed over the line . . . a west-bound train came suddenly upon a section of the line sunken out of sight. The train fell into the river and the engine-driver was killed." In 1886 a slide occurred which disconnected the line, but no watchman was then kept on that part of the railway. The engine ran a short distance down the bank, and the driver was scalded, but he was still at work on the line. Of the rest of the train, only the front end of one carriage left the metals. He also considered that the Author's statement that "at one time the tract of land on which the town of Ashcroft now stands began to move towards the river" (p. 6) was misleading; it had not, so far as he was aware, shown signs of moving. Mr. Cambie.

Prof. Boyd Dawkins, F.R.S., agreed entirely with the general conclusions of the Author as to the origin of the landslips and the best means to be adopted for preventing their recurrence in the future. It was perfectly clear they had been caused by the access of water to the argillaceous silt underneath the glacial strata which formed the surface. It was equally clear from their having followed the establishment of irrigation works, that they were due to the introduction of water in sufficient quantities to Professor Dawkins.

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[1] This communication was received subsequently to the remainder of the Correspondence, and too late to be placed before the Author for comment or reply.—Sec. Inst. C.E.

Professor Dawkins. soak down into the silt, which naturally was dry and hard, and ultimately to carry it away in the direction of least resistance into the nearest river. Had the natural *régime* not been disturbed there was no reason to suppose they would have occurred, as there were no traces of them in the strata which had not been artificially dealt with. The best way, and in these strata the only way, to stop them was to restore the natural conditions by putting a stop to irrigation in those portions of these strata which commanded the railway. Similar slips, it might be remarked, had from time to time occurred in Great Britain from the access of water to sandy beds resting upon clay, and had been remedied by cutting off the surface water from the beds in question. This was done many years ago in Bath, under the direction of William Smith, father of British geology. The solid geology of the valley of the Thompson River, carboniferous, cretaceous, triassic and other, had nothing to do with the cause of the slips.

Mr. Crowell. Mr. FOSTER CROWELL remarked that artificial disturbances of soil formation were rarely produced upon such a vast scale as in the cases so well described in the Paper; and the occasions were still rarer in which irrigation works might bring about destruction of such magnitude as occurred on the Thompson River. Nevertheless these land-slides formed striking and valuable object lessons to every engineer who had to deal with earthwork, and especially with the location and construction of railroads in new countries. In these cases the ultimate controlling cause was the admixture of water with a formation that was stable only when dry, thereby disturbing the conditions of equilibrium which had been reached in the processes of nature. Other causes might produce similar results in any given mass of soil that was in a state bordering on motion; among such causes were such obvious ones as the excavation of natural support and the imposing of the weight of embankments. He had seen a number of cases wherein the last-mentioned cause had been productive of great and long-continued damage to surrounding interests, which could have been avoided by due attention to the Roman dictum "quieta non movere" on the part of the engineer, either by adopting a change of location or by due precautions in distributing the additional weights. He would quote three instances; one occurred at Point of Rocks, near Brinton, on the Pennsylvania Railroad at the time of the rebuilding under his direction of the line to accommodate four pairs of rails, where formerly there had been but two; the original location had been balanced so that one line was established upon an excavated ledge and the outer one upon embankment, the formation being argil-

laceous rock with a very steep escarpment; the permanent way Mr. Crowell. was elevated about 70 feet above the foot of the cliff, extending from which were clay bottom lands of Turtle Creek—a sluggish stream which at that point was about 150 feet in width, and was spanned by an iron highway bridge resting upon substantial stone abutments; between the cliff and the stream was a village built along both sides of a single street extending parallel to the direction of the railroad; in building the two additional lines it was found desirable to place them symmetrically with reference to the old centre line and that brought the toe of the new slope, composed of rock from the cutting, close to the backs of the houses which were protected from it by a properly-designed retaining wall of masonry; the only feasible alternative would have been an undesirable tunnel or gallery through the Point of Rocks; soon, but not immediately, after the new embankment and retaining wall were completed complaints were received that houses in the village were being displaced because of them, but check measurements from the centre line proved that no movement had taken place in either the wall or the embankment, and the complaint was for the time dismissed; but there actually was a movement of the houses, on both sides of the street, some of which being of brick were ruined; those of wood were eventually moved back to their former positions; the entire material of the street and of the highway leading at right angles to the bridge, the near abutment of the bridge and the superstructure were all moved laterally several feet; the back wall of the far abutment was broken off above the bridge-seat by the movement of the superstructure, but beyond that no damage was apparent across the stream. Further investigation showed that the additional weight of embankment, acting vertically within its limits, had disturbed the equilibrium of the clay formation, on which a portion of it rested, and the pressure had expended itself in the line of least resistance laterally at a lower elevation than that of the toe of the embankment; the remedy, if it could have been applied in time, would have been to either avoid the overloading or carry the support down to the bottom of the clay. The second instance was that of a high embankment, also on the line of the Pennsylvania Railroad, across a level valley where a lateral movement, similar in its manifestations to that just described, was still active very recently, and had not ceased since the road was constructed, nearly fifty years ago. The third had come under his observation during an examination of the works of the Panama Canal, in 1889, several years after the abandonment of the excavation of the primary Culebra cutting. In

Mr. Crewell. preparation for the disposal of the spoil a series of parallel railways, built on successive benches at the mouth of the cut between Culebra and Paraiso, had been provided; some distance farther on, the line of the Panama Railway crossed the valley at a much lower elevation upon an embankment; comparatively little of the material had been taken out and deposited when the work terminated, but enough had been done to start a gigantic lateral movement in the entire width of the valley that not only wrecked all the extensive system of spoil railways, but displaced and destroyed the Panama Railway itself, so that for years thereafter it was necessary to maintain constantly a large force of section men to restore the line after the passage of every train, as was done at the time of his visit, and under his observation, twice in one day at an interval of rather less than eight hours. He had frequently seen cases of slips of serious nature resulting from unnatural saturation of the soil, though nothing approaching in magnitude those which the Author gave, and he had been the instrument of contributing to the cause of some of them by failure to properly intercept and lead off drainage water, or to take steps to prevent it from concentration in injurious quantities. These were often regarded as needless refinements of construction, except in cases where outside interests were to be considered and protected, but experience showed that no part of the cost of any earthwork was better expended than that judiciously applied to the matter of drainage. The Paper showed forcibly how widespread might be the results of a seemingly trivial agency, and how important it was not to lose sight of the destructive elements in the forces of nature.

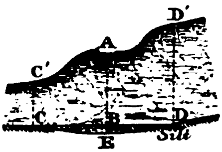
Professor Gaudard. Professor JULES GAUDARD, of Lausanne, thought the Paper shed new light on the causes of instability of ground subject to the percolation of water. The slides on the banks of the River Thompson were remarkable for their vast extent, for the fact of their being a result of artificial irrigation, for the length of time which had elapsed between the originating cause and the ultimate effect, and for the continuance of the movement as long as irrigation was carried on, so that the only remedy appeared to be to stop this irrigation, the extent of the slides being too great to be dealt with by drainage. Irrigation, in addition to its direct value for agricultural purposes, frequently formed a safeguard against disastrous effects of flood, as it permitted the retention and storage of at least a portion of the superabundant water, which, if allowed to flow away direct, would become destructive, instead of being gradually dissipated in agriculture and by evaporation. But it might be seen here that, in combating a danger in one direction, the effect might be to

bring another into existence, although the original intention was simply to fertilize a district otherwise arid. This danger did not arise from that portion of the water which was actually utilized for agricultural purposes, viz., for the fertilization of the layer of vegetable soil, as the slopes of this layer were not so steep as to be capable of sliding, but was due to the remainder of the volume filtrating into the ground, and, having penetrated the permeable sub-soil, reached a stratum, the character of which was altogether changed by the fluid. It might, however, be easily imagined that it would be difficult to deal effectually with this troublesome and disaster-working waste, for the ideal arrangement for a network of irrigation-channels was that the latter should gradually diminish the supply from its point of origin to the limit of the area affected. Although the extreme ramifications were laid out, as they should be, strictly in proportion to the demand upon them for irrigating the surface-layer of vegetable soil and no more, this did not apply to the channels nearer the point of origin of supply, which served as main ducts, or partially so. The beds of these ducts might, however, be lined with puddled clay. The delayed production of movement of land-slides had been exemplified in other instances. On the railway from Brunoy to Bois-le-Roi, in France, movements had taken place more than 4 years after the excavation of the cutting which had caused them. This might be explained by the extreme slowness of the process of percolation into a porous substratum (at a considerable depth) and without outlet; there it was subject to various influences, such as capillary attraction, &c., besides the action of gravity. This latter was far from being aided by the high pressures exerted by hydrostatic columns in deep fissures in the ground, for, as the liquid reaching the bottom of such a fissure penetrated further, it must open out a space to occupy; it could not do this by heaving up the ground, as its weight was less than that of the latter. The only way for it to penetrate a dry soil was by expelling the air in bubbles; but, in addition to the fact that the ascent of these bubbles became the more difficult in proportion to the distance they had to traverse, which was constantly increasing with the advance of percolation, the pressure itself diminished their volume and, consequently, their ascensional power of escaping through the liquid. Thus the pressure of a column of water, which acted so powerfully in detaching solid masses, imperfectly connected, seemed to have but little effect in accelerating infiltration in the depths of the earth; it was evident that it was not until more or less relative displacement of the component parts of the mass, pro-

Professor Gaudard.

Professor Gaudard. ducing disintegration, &c., took place, that the water could penetrate further and the process of infiltration became more and more advanced. On the other hand, although the flow was so imperceptibly small, it was also unceasing; and the small supply necessary kept it constantly in progress, and the water being unchanged, and practically immovable in the subterranean interstices, it had the effect of reducing the silt to slurry without removing any of its constituent elements. A soil with an inclined surface could only keep its form by the power of cohesion; all moisture, although it might be only partial, penetrating deeply into it had an inevitable tendency to reduce it to the level. Let it be supposed that from a ditch A, *Fig. 6*, there descended, through a permeable soil, filtration following the line A B, which at B reached a deposit of silt; there it spread out in all directions over the surface C D, and liquefied the silt to some depth, formed a semi-fluid layer or pocket C B D E, and consequently produced a change in the general conditions of equilibrium. On account of its incompressibility, a confined liquid was able to support a uniform load, whatever might be the pressure, but as it had lost its cohesion and frictional resistance, it had become incapable of sustaining an unequal load on the various points of a level surface, since it now followed the laws of hydrostatic equilibrium. Although, in the solid state, the layer C D supported at its extremities the varying heights of D D′ and C C′ of the permeable ground, it could no longer do so when it had become liquid; it then tended to become changed in form and to move, so as to lower the general centre of gravity of the mass. The superincumbent mass changed its shape; it sank at D′, it rose at C′; the fluid layer ran towards the lower end, it rushed from D, where it was compressed; it flowed to C, where it expanded and set up fresh percolations and opened up a passage for them.[1] This natural process went on and on; the subterranean liquid layer, or pocket, continued to increase in magnitude and to advance nearer and nearer to the valley, the movements at the surface of the ground continuing at the same time without cessation, and if in place of a regular slope the natural surface found a series of steps, the movement, instead of

Fig. 6.

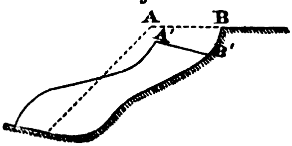


[1] The existence in certain places, notably in some districts of Algeria, of veritable subterranean lakes, appeared to be established. It seemed certain *à priori* that the surface of the ground above these sheets of water ought to be flat or nearly so; every elevation would not fail to sink in expelling the water situated below its heavy mass.

Professor Gaudard.

being continuous, would progress in a jerky or intermittent manner, a character which might be equally caused by the heterogeneity of the ground. As the water carried with it the silt which it had already dissolved, it was, in fact, a transport of solid matter, which was carried on under ground and which tended to reduce to the horizontal the visible surface. For this to raise itself at C′, above the original extremity of the saturated layer, it was necessary, however, that it should be sufficiently supported at the lower end. Should it happen that the point of upheaval, as it was displaced, approached the cutting of a road or railway or the ravine of a river, affording no support on the lower side, then the result would be a sudden sliding of the whole mass which had been rent vertically by the subsidence at the upper side; the mass would be more or less overturned and broken up in every direction by deformations and undermined at its base by the formation of a slippery plane surface, lubricated throughout by the slurry. In these sudden and extensive subsidences, which were presaged by comparatively small movements, the settlement was general over the whole surface; occasionally, however, it was noticed that the subsidence was unequal in extent, and, in the case of small land-slides, a portion, originally horizontal A B, *Fig. 7*, would, after the slide has occurred, assume the inclination A′ B′ sloping downwards towards the hill at the back; the face slope might also bulge outwards near the foot, the acquired momentum also permitting of its partial ascent of the counter scarp. In the case of the Canadian Pacific Railway, the origin of the land-slide being on the uphill side of it, it was altogether out of the question to attempt a remedy by carrying out simple works on the lower or valley side. Suppose, for example, an immense retaining-wall were constructed in the slope of the cutting, or in that of the river, it could only retard, to a very slight extent, the general subsidence, and as the surface of the ground would still possess a tendency to become horizontal; by travelling downwards, the upheaval of the lower ground would ultimately extend to the neighbourhood of the wall, and even if the latter were not bodily carried away, it would not prevent the disintegrated ground from being squeezed over its summit and obstructing the cutting or river. In order to grapple with the evil at its source and stop the slides, it would be necessary to drive a heading or culvert at B (*Fig. 6*) parallel to the irrigation duct A, with suitable gradients,

Fig. 7.



Professor Gaudard.

so as to intercept the percolation and allow it free outlet, the water would then be carried away without doing any damage. This subterranean aqueduct could prevent the water coming into contact with the silt by a lining of cement, but even if the water flowed over the silt, unprotected, it might be fairly assumed that, forming a rapid current, its effect would be to cause no more erosion than the River Thompson below did upon its banks, and that a protective covering of pasty clay would be constituted. Yet the custom was to put a concave bed of cement concrete, as more secure. Unfortunately, it was easily explainable why, in the presence of such extensive land-slides as those at the Black Cañon, recourse to treatment by drainage had been avoided, although it had so frequently done good service upon railway works elsewhere. In presence of the absolute necessity of keeping the permanent way of the Canadian Pacific in running order, it would appear as if for the time being at least, the cutting-off the supply of water was contemplated, as soon as it was feasible to do so, although it would entail a serious loss of money to sacrifice in this way the benefit of an established system of irrigation. It must also be remarked that drainage culverts, especially in those portions of the system where their direction was perpendicular to that of the general movement of the ground, run a great risk of being disturbed and broken, in which event they would be rendered worse than useless. Where there was a probability of this occurring it was advisable to construct the culvert in such a manner as to be accessible throughout its length, so that it could be kept in repair and free from obstruction.

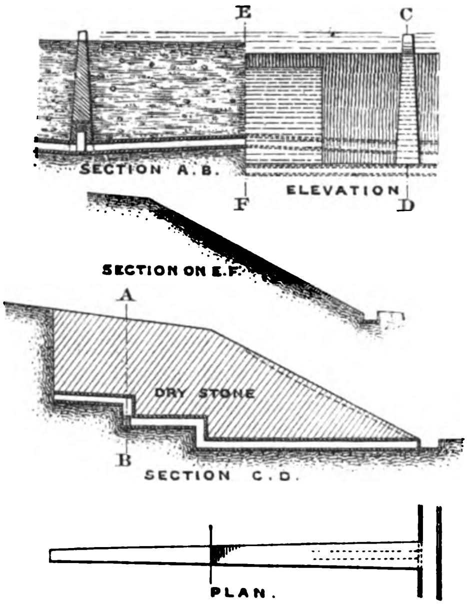
It was upon railway-construction works that considerable success had been attained in dealing with the slips which so frequently occurred in the slopes, but the circumstances in these cases were different from those of the valley of the Thompson, and, in some respects, opposite in character. It was not, as in the latter case, the artificial introduction of water into an area unsuitable for carrying it off which constituted the disturbing element and the direct cause of the land-slides (the valley and ravine of the river having existed before), but, on the contrary, in the case of railway construction, it was the subterranean water which was originally present, a state of things having been evolved under which the earth remained stable; further, the collecting of these waters, due to natural topographical circumstances, could not generally be checked; the disturbing element was the excavation of a cutting, which had upset the equilibrium of the ground, and it was for this reason that works of consolidation,

confined to the immediate vicinity of the part interfered with, could, at a moderate expense, prove efficient; for the disasters to be feared took place by commencing at the critical point and extending farther and farther; a primary partial slip was succeeded by a second of greater extent, and so on, so that by stopping the development of the first, the occurrence of the others was prevented, and thus it was only in a small area that provision had to be made for the free passage of percolating water, which would soften beds of silt, &c. The system of buttresses or transverse walls of dry stone, built at right angles to the slope of the cutting or the bulging hill and having a culvert at their base, was recognised at the present time as one of the best, since it supplied a method of drainage which dried and consolidated the surrounding soil, and, at the same time, a force of frictional resistance capable of withstanding the pressure which tended to push the slope into the cutting. With this object these walls, which intersect the unstable mass at regular intervals, should be carried down and founded upon a solid bed, so that they would not yield to the tendency of the adjacent mass to slide. This being so, each distinct portion of earth slipping could not slide without rubbing laterally against the faces of the two buttresses which enclosed it. This friction would afford sufficient resistance under two conditions, viz., (1) That the mass of earth be not converted into slurry, but preserve a certain amount of cohesion; (2) While being sufficiently cohesive, the mass of earth must yet exert against the buttress a lateral thrust great enough to produce the necessary friction. With regard to (1), it was necessary that the buttresses should be carried down sufficiently deep into the side of the hill, and be sufficiently near one another to perform their function of draining the space between them. Where necessary they might be connected together by a culvert or longitudinal waterway (*i.e.*, parallel to the railway) laid out with a falling gradient towards each buttress. However, where these drains ran the risk of occasionally becoming choked or broken, it might be preferable to do away with them, at the same time bringing the transverse walls closer together; they must, however, always be founded on the solid ground and made as accessible as possible. If the slope, although not sliding, exhibited in wet seasons a certain viscosity, the surface between the two walls which contained and retained them might swell and become convex. To counteract this deformation, a layer of stone pitching, either covering the whole slope or in the form of a pointed arch on plan, might be employed. This covering of massive stone restricted the tendency to swell out.

Professor Gaudard.

Professor Gaudard. It was a good plan to concentrate the weight by thickening the pitching at the centre, so that the greatest pressure was at the point of maximum upward thrust. Condition (2) was affected by the well-known uncertainty and difficulty of estimating the thrust of earth. Now instead of giving to these walls a constant thickness throughout, as was the usual custom, it would seem better to widen them out, that was to gradually increase their thickness from the upper to the lower part of the slope, so that the mass of earth (enclosed) between two consecutive buttresses would assume a trapezoidal form in plan. It would then form a wedge, which could not descend without becoming broken up. For similar reasons it would be advisable to give a batter to the upright faces of the walls, as the tendency of the earth is to descend, and this batter aids in sustaining it. *Figs. 8* showed the arrangements described. The pitching is shown as only covering part of the slope.

Figs. 8.



Professor Hull. Professor EDWARD HULL thought the Paper supplied an excellent instance of the essential interdependence of geological conditions and engineering art. It was remarkable that in this far-off region of Canada the same persistent enemy to engineering work was present as had to be faced in the British Isles; he referred to the boulder clay of the Glacial epoch. Engineers who had deep railway cuttings to construct or maintain in this deposit in Great Britain knew what a treacherous material it was to deal with; and the same appeared to be the case in North-West Canada. When first cut into it was often so solid and tough as to be able to stand like a wall; but a few months' exposure to rain and frost initiated a process of sliding which was interminable; and so it appeared along the line of the Canadian Pacific Railway. This

Professor Hull.

arose from the heterogeneous composition and absence of regular stratification in the boulder clay due to its glacial origin. He was not certain that the means described by the Author were the best for getting over the difficulty. The expense of the process of keeping the line clear over the "north and south slides" was great and continuous, while sudden slips and subsidences, like the case described in the Paper, would probably recur frequently. If possible, the best solution of the difficulty might be to avoid the enemy by tunnelling in the Cretaceous strata—from some point north of Nelson Creek to the eastern bend north of the Black Cañon. The distance would only be 1½ mile, and the work might be spread over several years without interfering with the present traffic. The account which the Author gives of the physical changes which had passed over this part of the Continent were of great interest, showing uprising and depression of the land, the filling to some extent, and re-excavation, of river valleys, the changes of climate, and the advances and retreats of the glacier ice in the Pleistocene epoch. These changes had to some extent their counterparts in Eastern America and Western Europe. From recent investigations [1] by Professors J. W. Spencer, A. Agassiz, Warren Upham, and other American geologists, it had been shown that the eastern borders of the American Continent had undergone great changes of level after the close of the Pliocene period, consisting of uprises of several thousands of feet, and subsequent depression, as shown by submarine soundings. The Paper showed that representative changes (not necessarily absolutely contemporaneous) had taken place on the north-western sea-board, and these went far to account for the occurrence of the glacial conditions of the Pleistocene period themselves.

Mr. Paterson.

Mr. Malcolm Paterson remarked that the porous gravel deposits which formed the bulk of the material of these great land-slides seemed to be those known to English geologists as "Kaims," or "Eskers," in which it was supposed that the substance of moraines, or boulder clay—the "till"—was blended with marine gravels. Glaciers had descended to the sea-level and launched themselves and their burden of débris into tidal waters, by whose action such débris had become so washed and scoured that the angular boulders had become rounded into shingle, and the "till" had been largely changed into a perfectly free and porous gravel, with pockets of argillaceous sand and thrown into mounds and terraces. He had recently driven a short tunnel in an "Esker," parallel with and

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[1] Spencer, "Reconstruction of the Antillean Continent," Geol. Mag. 1897; Upham, "Cause of the Glacial Period," Trans. Vict. Inst., 1897.

Mr. Paterson. 12 yards or so from the River Aire at Shipley; in the heading of which the river-water freely entered and as freely flowed out, as the river-floods rose and sank. The movement of so vast a mass of porous material as that described in the Black Cañon upon its inclined bed of silt was a natural result, such silt being converted by saturation under enormous pressure into a kind of soft soap, upon which the "slide" would be aided by the hardness of the material below it. With so slight a rainfall, the natural stability of the gravel and its bed of silt, as explained by the Author, was clear, as also its failure under the artificial deluge caused by irrigation over a surface so porous.

Mr. Reade. Mr. T. Mellard Reade thought the land-slides described in the Paper had occurred under very unusual conditions. The silt which appeared to be the cause of the trouble, whether as boulder clay forming the matrix of the boulders or as a secondary deposit without boulders, was described by the Author as being, under ordinary conditions, perfectly dry except near the surface. In every deposit in Great Britain, boulder clays, silts, sand, gravel, or even rock, held a large percentage of water. It was well known to those who had examined clays, and mechanically analysed them, that a moist lump of clay, if thrown into water, would melt very slowly, whereas, if thoroughly dried, and then placed in water, it would disintegrate and fall to pieces immediately. The resistance of moist clay to disintegration was shown by the clay boulders, which were often formed by the rolling of fragments of clay on the seashore. The abnormally dry silt or boulder clay composing the terraces of the Thompson River, when subjected to artificial irrigation, evidently broke up in a similar manner to dried lumps of British boulder clay when immersed in water. That this was the true explanation of the great slides was shown by the fact, mentioned by the Author, that when the clay or silt naturally received a thin coating of moist clay it would withstand the action of water in a remarkable manner.

Mr. Robson. Mr. John J. Robson had practised in British Columbia during 1888–89 and had a fair knowledge of the south part of the province. The cause of the slips was, indeed, no ordinary one, and apparently only by careful observation and experiment in the laboratory could the peculiar action of this silt when saturated with water, and likewise when exposed to the elements, have been discovered. Apart from the dangerous nature of driving tunnels so as to drain the slip in loose moving earth, it would be necessary that such tunnels should be low enough to drain the bed of the slip in order to be effectual; but as the bed of the slip was at or about low-water level of the river it appeared impracticable, and

even if it were possible another danger would arise when the spring freshets occurred; the river, then rising as much as 70 feet or 80 feet would again surcharge the bed of the slip with water by means of the drainage tunnels, and the last state of the case would be worse than the first. In the final paragraph the Author pointed out the only remedy, viz., to stop the irrigation, and in this he strongly agreed. This he interpreted as an absolute stoppage of the irrigation ranches, and not only cutting off the water. The latter course was impossible, in consequence of the open and porous nature of the top soil, underlaid with sand and gravel. On such land the water soaked in and found its nearest way by underground channels into the back and bed of the slip; and there was also the leakage from the irrigation ditches, which were very rudely constructed by the farmers, and were seldom water-tight, so that the only remedy was to entirely stop the irrigation. In the Paper it was stated that the two largest slides occurred before the construction of the railway, and he would have thought that when it was found to be imperative to carry the railway across these slides, and the cause being known, that the railway company would have at once bought out the ranchers instead of continuing such costly maintenance works, for in those early days of British Columbia all the ranchers of the district could have been bought out for one-half the money which had already been expended. It naturally arose whether these land-slides could have been avoided in locating the railway, and in this case he did not see that it could have been so arranged without carrying it at a higher level by some 300 feet or 400 feet than at present, which, apart from the inconvenience of such a route, would have been a serious obstacle to the general down-grade from Donald to Vancouver (a fall of 2,500 feet in 458 miles). In other cases, however, the railway had been carried over old land-slips which might have been avoided; he particularly referred to one near Port Harvey, on the Fraser River, some 50 miles east of Vancouver, which he had examined; and, although no further subsidence might have occurred, yet he considered that engineers were not justified in running such unnecessary risks in order to save $\frac{1}{4}$ mile of cuttings. The Pacific section of the Canadian Pacific Railway was intensely interesting to the engineer. The route was beset with natural obstacles and difficulties, and some idea of the nature of the work might be imagined from the fact that between Donald and Vancouver there were over 1,900 bridges, some of which were over 200 feet high and others over 2 miles long. Indeed, no engineer would have selected such a route, as there was no doubt that a much easier one existed

Mr. Robson.

Mr. Robson. farther north; but political motives had influenced the selection. The Author touched upon the topography and climate of the country; respecting the former it was a veritable sea of mountains, whilst the interior plateau was only a comparative term, indicating a stretch of high hills and undulating country lying between the more rugged and lofty mountain ranges; it was, indeed, the roughest and most rugged country in the world. When, in addition to the foregoing conditions, the dense forests on the Pacific coast were added, with the trees between 200 feet and 300 feet high, and fallen timber (the accumulation of centuries) so thick in places it was possible to go for miles without touching the ground, the work of the engineer was difficult and arduous in the extreme. The climate was, however, so delicious that such drawbacks as the above were forgotten; it might well be likened to an improved Devonshire (on the coast), the greatest heat registered being about 90° F., whilst in the winter it seldom fell so low as 20° F. The climate was, as the Author stated, rather less genial in the interior, but taken as a whole he had never heard of nor experienced a better.

The Author. The AUTHOR, replying in writing to the Discussion and Correspondence, thought the last paragraph of the Paper had been misunderstood. It had been written with the experiences of the Ashcroft, and with the Great Northern slide fully in mind, as well as the nature of the material to be dealt with in the slide, and hence by "cutting off the irrigation water above" was meant the absolute stopping of all irrigation in the neighbourhood of the slide, for the reason that the nature of the material, as described in the Paper, was such that no other means suggested would be effectual. It was not necessary to add to the description of the nature of the material composing the slides, or the peculiar action of the water upon it. The case was most clearly and forcibly expressed by Prof. Jules Gaudard. He felt gratified at the kind and complimentary discussion of his Paper; but he could not agree with some of the opinions expressed as based upon the facts he had stated. He had had much experience in dealing with ordinary land-slides while in charge of the construction of a portion of the Cincinnati Southern Railway through the coal measures of the Cumberland Mountains in the States of Kentucky and Tennessee, during the years 1874–1880, and he had made a somewhat careful study of the great mud tunnel upon that road. These slides, in most instances, had been caused, during the building of the road, by cutting through the lower edges of the strata, when the heavy rains of the winter wetted the layers of blue clay, thus lubricating the inclined plane on which the super-

incumbent mass was resting, when in some instances hundreds of acres slid down the mountain side into the valleys below. In other cases solid masonry tee-abutments, built upon clean and solid bed rock, were carried off their foundations and moved bodily down the hill by the force of a slide behind them. These cases were similar to those described by Mr. Foster Crowell, and to these in general were applied the usual remedies, such as drain ditches above, tunnels, drifts and drains below, with very satisfactory results. None of these remedies, however, would be of service if applied to the great slides under consideration in British Columbia, on account of the nature, condition and position of the material composing them. The cutting of a drain ditch around the back of the slip to take the water off would be more than useless: (1) The water causing the damage was that applied upon the cultivated fields (p. 3), and after being once applied could not be collected into a drain, for it rapidly percolated downwards into the boulder clay and silt underlying the top soil (p. 4). (2) If the water was collected into an ordinary ditch it would work more damage than good in such clay and silt. This method, a ditch filled with water running around the back of the mass, was that used in England, and especially on the great clay banks of the Isle of Wight, for the purpose of bringing down great masses of clay for commercial purposes. If, as had been suggested, this ditch, and also the small canals leading to the farms, were lined with puddle, cement, or asphalt, and the water kept in them, no irrigation could be accomplished, for, as soon as the water should be taken from the ditch and spread upon the fields, the damage would be done. Hence this remedy, if carried back far enough to be effectual, meant simply cutting off the diseased tail of the dog close up behind his ears—which was the true and only real remedy. Careful study of the nature of the material, as explained in the Paper, and so forcibly expressed by Prof. Jules Gaudard, would show that no system of tunnel drains, drifts or surface drains through or at the lower side of the slide would be of value in such a moving mass of silt, there being no "stable bed inclined towards the river" on which it slipped; but "the mass would be more or less overturned and broken up in every direction by deformations and undermined at its base by the formation of a slippery plane surface lubricated throughout by the slurry." If such drains and tunnels were partially successful for a time, they would not be permanent, for in such material no system of tunnel drains would carry off all the water unless built so close together as to form one complete cellar under the whole mass, which would be out of the question. Hence a portion of

The Author.

The Author. the water would sink lower—even below the level of low-water in the river. After a time a new "subterranean liquid layer or pocket" would be formed lower down, and the whole operation would be repeated. As stated in the Paper (p. 9) and remarked by Prof. Boyd Dawkins, "the solid geology of the valley . . . . had nothing to do with the cause of the slips." But the position and the condition of the solid geology at this time underlying the great mass of silt became a very important matter of study in determining the proper methods to be applied for curing the evil as it now exists. Therefore he could not agree that the position and action of the ancient Pliocene river was unimportant. It was only by the study of every known detail, both ancient and modern, in such a problem as that under consideration, that a true knowledge of the facts could be arrived at, or the proper estimate of the proper remedies formed. It was from the study of this ancient Pliocene river bed that had led him to conclude that no tunnels or drains from below would be effectual, for on examining other details it seemed that the mass of silt under the slides extended below the present bed of the Thompson River, and was being forced up into the river at its edge. The neglect by the Dominion Government of the mere detail that above this one old south slide a 35-acre field was being constantly irrigated—a field at that time worth perhaps £35—had cost the railway company some £10,000. It was not his purpose to criticise the Dominion Government, which first built the railway, or the Canadian Railway Company, which had since worked it; but, in justice to the engineers who first built and had since had charge of the railway, it must be said that they at first and continually recommended the purchase and wiping out of the farms entirely. Whether this want of action had been due to false economy, neglect of detail, or political necessities, was unknown. The possibility of locating the railway on the opposite side of the Thompson was out of the question. The nature of the ground was the same, and, since being irrigated, large slides had occurred also on that side. As far as the old slides were concerned, the location was correct; but the land should have been bought at first, and the farms, as such, wiped out of existence. The absence of sufficiently accurate borings precluded his illustrating his reply by cross sections through the slides; he did not, however, consider they would add to the information he had given in the Paper in elucidating the subject. He could only repeat his conclusion that there was no way of preventing the disastrous effects of these land-slides upon the railway except by stopping entirely all irrigation of any lands whatsoever above them.

21 December, 1897.

Sir JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S., President, in the Chair.

(*Paper No. 3030.*)

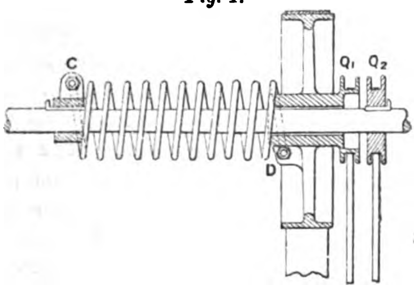
"A New Transmission Dynamometer."

By WILLIAM ERNEST DALBY, M.A., B.Sc., Assoc. M. Inst. C.E.

MANY transmission dynamometers have been constructed in which the deformation of a spring is used to measure the work transmitted. Their mechanism may be divided into two distinct parts—(1) the measuring springs and the apparatus fixing them to the several parts of the dynamometer; (2) the apparatus used to measure the deformation of the spring. It is of a new mechanism for the latter purpose that this Paper particularly treats.

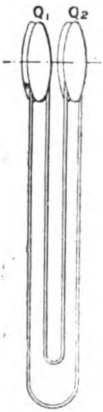
The problem presents itself in the following form:—One end of a spring, *Fig. 1*, is fixed to the shaft at C, and the other end is fixed to the loose pulley at D. Consider the shaft as driving a machine through the spring, pulley, and belt. A turning moment applied to the shaft twists the spring, until the applied twisting moment is equal to the resisting moment at the pulley. Then the pulley and shaft may be turned together without relative angular displacement. If there be any change in the moment of resistance at the pulley, there must be a corresponding change in the applied turning moment, and the spring twists or untwists until the equality of the two moments is established. The torque is proportional to the relative angular displacement of the ends of the spring, and the special problem is to measure this displacement when the spring is rotating. This is the same thing as

Fig. 1.



measuring the relative angular displacement of the pulley and the shaft, since one end of the spring is fixed to the pulley, and the other end to the shaft. To do this, let two grooved pulleys Q_1 Q_2, of exactly the same diameter, be fixed, one to the pulley and the other to the shaft (in *Fig. 1*, Q_1 is shown cast with the pulley). Place over these pulleys an endless steel band in such a way that there are formed two hanging loops, the parts of the band forming one loop leading one to the pulley Q_1, and the other to the opposite side of the pulley Q_2, as shown in *Fig. 2.* The band is placed over the pulleys Q_1 Q_2 in the same way as the endless chain is put over a pair of Weston differential pulley blocks. However quickly the pulleys may be rotating, so long as there is no relative angular displacement between them, the distance apart of the loops will remain the same; for one pulley winds on just as much band as the other winds off. The slightest relative angular displacement of the pulleys alters the distance between the loops; for then the quicker pulley is winding on more band than the slower one winds off. If a guide-pulley be placed in each loop, suitably constrained to move in a slide to avoid lateral oscillations, the distance apart of the loops may be easily measured by attaching a point or index to the frame of one guide pulley, arranged to read against a scale attached to the frame of the other.

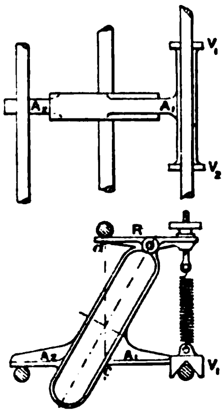
Fig. 2.



A dynamometer constructed according to the foregoing principles has been erected in the Engineering Laboratory at Cambridge. A dynamometer pulley was substituted for an ordinary pulley on the main shaft, and drove a dynamo. The shaft was driven by a high-speed gas-engine at 500 revolutions per minute. The pulley was mounted on ball-bearings to minimize the friction between it and the shaft. To prevent the band from creeping or slipping, the pulleys Q_1 Q_2 are sprocketed, and the steel band is correspondingly punched. The length of the endless band is adjusted so that the measuring apparatus may be placed in a position convenient for observation. Guide-pulleys were placed in the hanging loops and their weights keep the bands taut. A steel rule was attached to the frame of the upper pulley, and a point or index to the lower pulley to observe the change in the distance between the pulleys. A calibration must be made for any particular spring, so that the value of the scale divisions may be interpreted in foot-pounds.

As the loops lengthen or shorten, the frames carrying the pulleys must slide up and down quite freely, and without side shake. For if one loop shortens, the other lengthens by the same amount, and the pulley only keeps in touch with the lengthening loop by virtue of its weight. Consequently a tendency to stick at any point would prevent its following the loop, and would impair the scale readings. To give this sliding freedom, combined with a good fit, a kinematic slide has been devised. The slide-bars are formed of three turned rods held together by suitable end-plates, so that they form a rigid frame of three parallel bars. The frames carrying the guide-pulleys slide on these bars. Each frame touches the bars at six points only; the rigid portion of the pulley frame having five points of constraint and therefore one degree of freedom, while a spring contact at the sixth point furnishes the necessary pressure against the five points of constraint. *Figs.* 3 show one of the frames used in the measuring apparatus of the dynamometer referred to above. It carries an arm A_1, each end of which is formed into a V-groove, V_1 V_2. If the frame be held against the bar, so that these V-grooves rest on it, there is contact between the bar and the frame at four points only, viz., one point in each face of each groove. The faces are rounded slightly to ensure this. The frame has now two degrees of freedom, viz., a sliding motion parallel to the bar, and a rotation about the bar. Suppose the frame turned about the bar until the arm A_2 is brought into contact with it. There are now five points of contact so long as the frame is constrained to touch the bars; and it has only one degree of freedom, viz., the sliding motion parallel to the bar. It is kept in contact with these bars by the tension of a spring holding the piece R continually in contact with the third bar. The spring may be regarded as an internal force in the frame constantly exerted to lengthen the dimension *c d*. If the frame be in its highest position, the tension of the spring may be so adjusted that the frame floats slowly down to the bottom; the spring yielding to all the smaller irregularities of parallelism in the three bars, but constraining contact at the six points during the whole motion.

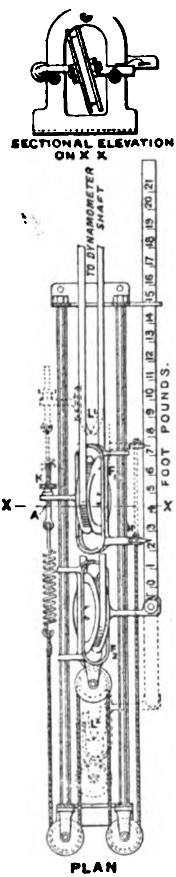
Figs. 3.



In this form of measuring apparatus the guide-pulleys are kept

in contact with the loops by their weight only. It is desirable to keep their mass as small as possible, so that they may follow sudden alteration in the position of the loops without straining the band; at the same time the force constraining them to follow the loops should not be reduced, *i.e.*, although it is desirable to reduce the mass, it is not desirable to reduce the constraining force. These conditions may be fulfilled by making the pulleys light, and constraining them to follow the loops by means of a spring. The spring should be arranged so as to cause a constant constraining force. Taking advantage of the fact that the upward movement of one frame is always equal to the downward movement of the other frame, the spring is arranged to act in the way illustrated in *Figs. 4*. A constraining spring is fixed to the frame at A_1 by an adjusting screw K. A cord is fastened to the other end of the spring and led round small guide-pulleys, and fastened to the frame F_1 at H. Two of the guide-pulleys are mounted on the end-plates of the slide-bars, and the third is mounted on the frame F_2. Suppose the apparatus to be running in the position shown in full lines. The tension on the spring constrains the pulleys to sit in their respective loops. Suppose in consequence of a change of torque on the dynamometer shaft, the upper loop shortens to the position L_1; the lower loop will lengthen by an equal amount, and move to the position L_2. The distance between the points H, A, in the new positions of the frames F_1 and F_2 measured along the cord, remains the same. Consequently, in the new positions of the frames, the tension on the spring, and therefore on the cord, remain constant. It follows that through the whole range of motion of these pulleys the constraining force is constant, and may be adjusted to any amount by adjusting the tension on the spring.

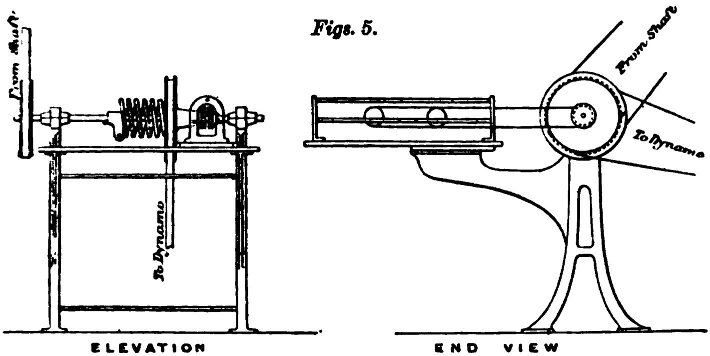
Figs. 4.



The measuring apparatus is now independent of gravity, and can be placed horizontally or vertically, or at an angle, the constraining force of the spring keeping the endless band taut. The scale is shown fixed to the frame F_2, and the index to the frame F_1.

Self-Contained Dynamometer.—A dynamometer constructed so as to be self-contained is shown in *Figs. 5.* It is interposed between a countershaft and a dynamo. The dynamometer pulley is mounted on ball-bearings. The steel band is brought away horizontally, and the guide-pulleys in the loops, frames, and controlling spring are arranged in the same way as shown in *Figs. 4.* Stops are arranged on the dynamometer shaft, and on the pulley P, to limit the relative angular displacement of the spring to about three-quarters of a turn. The diameters of the sprocket-wheels Q_1 Q_2 are such as to give to the loops a total range of relative linear displacement of about 10 inches. The springs shown in *Figs. 1* and *5* connecting the dynamometer pulley to the shaft are arranged with their axes coincident in each case with the axis of the shaft, so that the deformation produced by the applied torque

Figs. 5.



SELF-CONTAINED DYNAMOMETER.

is in each case a twist. This arrangement has the advantage that it practically eliminates the effect of the centrifugal force acting upon the spring. The spring measuring the torque may be arranged to act in tension if found more convenient. The relative angular displacement of the pulley and the shaft would, in this case, be limited to about 30°, but it is only necessary to properly proportion the diameters of the sprocket-wheels Q_1 Q_2, to obtain as great a range of motion of the loops as is desired.

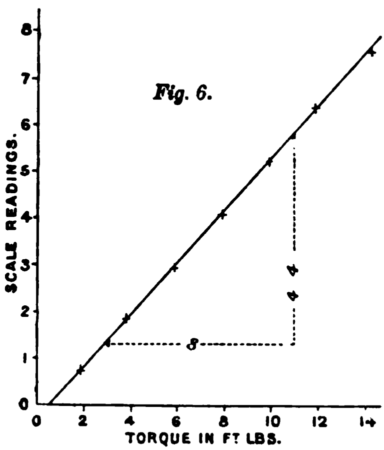
Calibration.—The scale of the dynamometer may be calibrated by fixing the shaft and applying a known torque to the pulley. The dynamometer shown in *Figs. 5* was calibrated in the following manner. The shaft was fixed, and a band of webbing was placed round the pulley, one end being fastened to the pulley, the other end hanging free. The free end was loaded gradually with known

weights, and a reading was taken on the dynamometer scale for every change in the loading. Thus the torque was known for a series of points on the scale. The values of the torque and corresponding scale readings are given in Table I. When the maximum load was reached, it was decreased gradually, the corresponding scale readings being taken at every change. The radius of the applied load was 0·5 foot. The readings are given for changes in the load of 4 lbs. up and down.

TABLE I.

Load.	Torque.	Scale Reading.
Lbs.	Foot-Lbs.	Centimetres.
0	0	Spring against stop.
3·81	1·9	0·77
7·81	3·9	1·83
11·81	5·9	2·94
15·81	7·9	4·08
19·81	9·9	5·20
23·81	11·9	6·32
27·81	13·9	7·43
23·81	11·9	6·36
19·81	9·9	5·23
15·81	7·9	4·11
11·81	5·9	3·00
7·81	3·9	1·87
3·81	1·9	0·77
0	0	Spring against stop.

From these figures the calibration curve, *Fig. 6*, has been plotted, from which it appears that a change in torque of 8 foot-lbs. produces a change in the scale reading of 4·4 divisions. Therefore one scale division corresponds to a change of 1·8 foot-lb. in the torque acting on the dynamometer shaft. The scale used was an ordinary centimetre scale divided into millimetres. Knowing the constant, it is easy to construct a scale such that one division corresponds to a change of 1 foot-lb. in the torque.



The advantages of the new dynamometer are—(1) the scale readings are strictly proportional to the torque; (2) the scale may be made very open; (3) the scale may be placed in any position convenient for observing it, being independent of the position of the dynamometer pulley; (4) the scale and index are at rest except during the time a change of torque is taking place; (5) the

instrument may be arranged to measure very small changes in the torque without measuring the whole torque.

The following experiment with the dynamometer shown in *Figs.* 5 was made by Messrs. Couper and Roget in the Engineering Laboratory at Cambridge. The constant was 1·81 foot-lb. per

TABLE II.

Speed of dynamometer shaft, 622 revolutions per minute.
" dynamo " 1,220 " " "

Conditions.	Dynamo-meter Reading.	Torque on Dynamo-meter Shaft.	Torque reduced to Dynamo Shaft.	Speed of Dynamo Shaft.	Work per Second.
	Centi-metres.	Foot Lbs.	Foot-Lbs.	Radians per Second.	Foot-Lbs.
Rest	0	0	0	0	0
Fields unexcited, brushes off .	0·5	0·91	0·46	128	59
" excited, brushes off .	0·7	1·27	0·65	128	85
" " brushes on .	0·9	1·63	0·83	128	106

centimetre. The instrument was used to find the work done on a small series dynamo, and simultaneous observations were made of the speed, electromotive force, and current, along with the dynamometer reading. A preliminary trial was made to ascertain the belt losses, the losses in eddy currents, hysteresis, and the losses with the brushes on but the circuit open. The dynamo was separately excited. The results of this trial are given in Table II, which shows that the belt loss and mechanical losses in the dynamo are at the rate of 59 foot-lbs. per second. The losses due to eddy currents and hysteresis are at the rate of 83 − 59 = 24 foot-lbs. per second; and the losses due to currents induced in coils short circuited by the brushes are at the rate of 23 foot-lbs. per second.

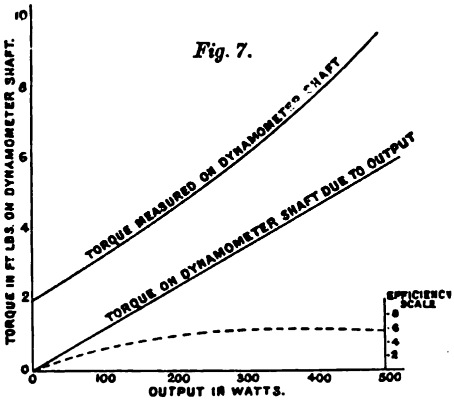


Fig. 7.

The results of the main experiment are given in Table III,

and are shown graphically in *Fig. 7.* The output in watts is reduced to the equivalent torque at the dynamometer shaft.

TABLE III.

1	2	3	4	5	6	7
Speed of Dynamometer Shaft.		Output from Dynamo.			Torque equivalent to Output reduced to Dynamometer Shaft.	Observed Torque on Dynamometer Shaft.
Revolutions per Minute.	Radians per Second.	Amperes.	Volts.	Watts.	Foot-lbs.	Foot-lbs.
622	65·0	0	55·5	0	0	1·98
622	65·0	2·8	51·0	142·7	1·62	3·81
620	65·0	5·3	47·0	249·0	2·82	5·43
620	65·0	7·5	45·5	341·5	3·88	6·73
615	64·3	9·5	43·5	413·5	4·73	7·81
610	63·7	11·3	41·5	469·0	5·42	8·92
608	63·6	12·7	39·0	496·0	5·74	9·44
610	63·7	12·2	40·5	494·0	5·71	8·73
618	64·6	9·6	43·0	413·0	4·71	7·81
620	65·0	7·8	45·5	356·0	4·04	6·92
622	65·0	5·5	49·0	270·0	3·06	5·63
622	65·0	3·0	52·0	156·0	1·77	3·81
622	65·0	0	56·0	0	0	1·98

It will be observed that the output was gradually increased, and then diminished. The torque equivalent to the output is reduced to the dynamometer shaft by the following formula:—

$$\text{Equivalent torque in foot-lbs.} = \frac{C \times E \times 0{\cdot}73}{\omega_o},$$

where C is the current in amperes, E the electromotive force between the terminals, and ω_o is angular velocity of dynamometer shaft in radians per second.

For any set of observations, the equivalent torque may be compared with that actually acting on the dynamometer shaft, and the efficiency of the apparatus between the dynamometer shaft and the terminals may be deduced. The curves in *Fig. 7* are plotted from columns 6 and 7 against the output in watts. The dotted curves show the ratio between pairs of ordinates, and its ordinates represent the efficiency of the apparatus for different outputs.

The thanks of the Author are due to Prof. Ewing, M.A., M. Inst. C.E., for allowing the two dynamometers described in this Paper to be made in the Cambridge University workshops.

The Paper is accompanied by eight drawings and two photographs, from which the *Figs.* in the text have been prepared.

[DISCUSSION.

Discussion.

Sir JOHN WOLFE BARRY, K.C.B., President, was sure the members would accord a hearty vote of thanks to the Author for his interesting Paper. Sir John Wolfe Barry.

Professor DALBY showed the apparatus and described it in action. Prof. Dalby.

Professor W. E. AYRTON thought the apparatus exhibited and described was distinctly ingenious, because the Author had taken advantage of well-known devices to combine them together in a new way. There were many dynamometers having springs; there were even some with a spring coiled round the axis of rotation, such as, for example, the dynamometer of Prof. Smith, described[1] by him in November 1888. Indeed, in Prof. Smith's dynamometer there were two springs, one coiled one way and one the other around the axis of rotation, so as even to compensate better for any errors arising from centrifugal force than the Author's arrangement. The arrangement Q_1 and Q_2, *Fig. 2*, had also been used in transmission dynamometers. But the use of the arrangement, not for the well-known purpose of transmitting the power by the endless belt with its two loops, but for the purpose of measuring in a very convenient way the relative position of one pulley to another—measuring this, as explained by the Author, not only at the pulleys, forming the dynamometer proper, but, if desired, at a distance from them, had, so far as he knew, not been previously resorted to. In all transmission dynamometers the main difficulty was the friction. It was almost impossible to calibrate such an instrument, as usually constructed, statically. By applying forces to the two pulleys and observing the deflection of the pointer, various results would be obtained with any ordinary transmission dynamometer because of the excessive friction. It had therefore to be calibrated while running, when there was a certain amount of jarring, so that the friction was overcome. But then the calibration was difficult because there was often considerable vibration of the pointer. The Author's dynamometer could clearly be calibrated, and, in fact, it had been calibrated, statically, by loading it with weights and observing the positions of the pointer; and, from this statical calibration, it was possible to Prof. Ayrton.

[1] Minutes of Proceedings Inst. C.E., vol. xcv. p. 56.

Prof. Ayrton. correctly infer the torque transmitted when it was running. He should think that the friction was so small that it was hardly necessary to introduce any sort of vibration to overcome it when calibrating the dynamometer statically. [Prof. DALBY assented.] It was not necessary even to introduce a small amount of vibration when calibrating the dynamometer because of the extreme perfection of the geometrical-slide indicating arrangement. He thought, however, that the absence of any damping would constitute a difficulty with that very perfect indicating mechanism. Supposing, instead of having the very charming and perfectly steady-running motor to drive the dynamo through the dynamometer, there was a single-cylinder steam-engine—had the Author tried whether, in such a case, the pointer, in consequence of the total absence of friction, was not vibrating through a very large angle? Friction was an imperfect method, but it was a very effective one for damping oscillations; but for such a purpose as had been mentioned, where there was a steady torque applied, there was no doubt that the arrangement was delightfully simple, using well-known devices and attaining the result in a new way—using, in fact, the endless belt for the purpose mentioned by the Author, of showing the relative angular motion of one pulley to that of the other. With regard to the trials detailed in the Paper, he thought that if the line in *Fig. 6* were drawn more accurately the value 4·4 should be 4·5. One scale division corresponded with a change of 1·79 foot-lb. instead of 1·81 foot-lb. Curves which had been drawn for him showed that the ascending and descending observations were very similar, proving that there was an extraordinary absence of friction. The dynamometer readings in Table II were of the order of $\frac{1}{2}$ centimetre—0·5, 0·7 and 0·9—and yet the torques on the dynamometer shafts in foot-lbs. were worked out to three significant figures. That would mean measuring to $\frac{1}{1000}$ centimetre. Unless the Author had actually in his experiments measured to such a degree of accuracy, unless his charming geometrical slide enabled him to measure $\frac{1}{1000}$ centimetre accurately, he did not see how it was possible to give the work in foot-lbs. per minute to three significant figures. Nor could he understand why, when the brushes were put on and a difference in value was found, the Author considered it to be entirely due to the current induced in coils short-circuited by the brushes. Surely this difference would mainly be due to brush-friction. Then he thought that in calculating the efficiencies it might be advantageous to mention that the power expended in the excitation of the machine was not included. In speaking of the efficiency

Prof. Ayrton. of a dynamo, the ratio of electric power given out to the mechanical power supplied was generally meant. In the case of a motor it was the other way. If, however, the machine was separately excited, the power spent in the field-magnets ought, he was of opinion, to be included. He would suggest that it might be well to distinguish carefully between a foot-lb. and a lb.-foot. Throughout the Paper, and indeed, in many Papers and books on engineering, torque was measured in foot-lbs. That appeared very misleading, especially when, in the same Paper, work was being dealt with, which of course was not torque, but a totally different quantity. He thought it would be better to speak of foot-lbs. when energy or work was meant, and of lb.-feet when the moment of a couple was referred to.

Mr. Anderson. Mr. E. W. Anderson desired to emphasize the inconvenience that would arise in the general use of the instrument from its being so exceedingly sensitive. In testing a dynamo the load might be kept perfectly steady, and admirable results could be obtained; but in dealing with such a machine as, say, a belt-driven air-compressing pump with an inadequate fly-wheel, he was afraid the recording apparatus would jump about in a surprising manner, and there would be great difficulty in obtaining a proper result. In such a case, where the variation was rhythmic, some form of dashpot applied to the dynamometer might enable an average reading to be taken satisfactorily; but where the variation was irregular even this would not be much help, and it would be almost impossible to obtain any reliable indication of the average torque. Some years ago he had assisted in the trials of disintegrators, grinding (amongst other things) bones, and the work was very variable, while at times a large piece would get in and cause the recording gear of the dynamometer to fly about all over the scale. Only a proper integrating arrangement could give a result under such circumstances, supplemented as a check by a continuous diagram drawn on a paper strip which could afterwards be integrated to obtain the average load through the run. If the Author could arrange such an apparatus in connection with his instrument it would make it much more valuable. For a steady load it appeared to be an exceedingly beautiful contrivance, and he heartily congratulated him upon it.

Mr. Bryan Donkin. Mr. Bryan Donkin thought the instrument could be easily calibrated, as it was almost frictionless. It had many points of merit, but he would be glad to know how the instrument would work if 50 HP. were being transmitted, and how it would operate when power varied between 50 HP. and 25 HP. in 1 minute or

Mr. Bryan Donkin. 2 minutes. He should be glad to know if any experiment had been made as to the maximum speed; and the maximum power at which the instrument had been tested? It appeared that it might be arranged with a pencil to register on paper the horse-power continuously. He also asked whether the band could be applied to indicate at a long distance. In the case, for example, of a steam-engine house and an office 100 feet distant, could there be an arrangement to transmit and register the power to a considerable distance from the load?

Mr. Burstall. Mr. H. R. J. Burstall had expected, from the title of the Paper, to find a new solution of the difficulty experienced when advising as to the power required in motors for driving machinery which had before been driven by a main engine, and had hoped to see a description of a machine which could be practically used for that purpose. The Paper was really a description of an apparatus for measuring the relative positions of two rotating pulleys, because the principle of either a coil spring or a spring in tension for use in a transmission dynamometer was old. Practically only two solutions were available of the problem of finding how much power a machine absorbed, either to indicate the main engine under various conditions, which was a matter of taking differences on an indicator diagram and therefore difficult to obtain accurately, or, when current was available, to find the current required by an electric motor driving the machine. The apparatus which the Author had shown was, however, from a kinematic point of view, an exceedingly clever one. He should be glad to know at what speed the Author had been able to run the sprocket pulleys and band, because the only way in which he could obtain an open scale was to increase the diameter of the pulleys, and therefore the speed of the band. To transmit or measure a large power a very heavy spring would be necessary, or possibly even the torsion of the shaft itself, which had been employed. If so, a very delicate apparatus would be needed. Perhaps the Author could state whether he could make the apparatus sufficiently delicate to measure the torsion of a shaft when transmitting power.

Mr. Beaumont. Mr. W. W. Beaumont remarked upon the salutary departure the Paper represented from the ordinary practice of writing a history of the world in order to be able to describe a new method of making a hole in it. According to the old practice an Author, in describing an instrument like that exhibited, would first make himself thoroughly tired by writing descriptions of everything else in the way of transmission dynamometers. A good example

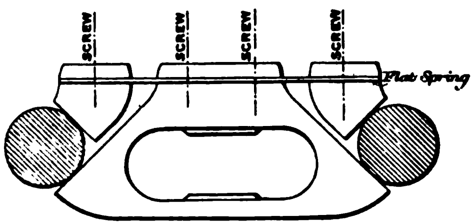
was set by the Author by commencing straight away with his subject, which was the description of a new thing. Nine years ago he had read before the Institution a Paper[1] on the other half of what might be called the power dynamometer field, viz., absorption or friction-brake dynamometers, and on that occasion Professor Smith described the transmission dynamometer which he had invented, and which had been referred to by Professor Ayrton as one containing several features of great ingenuity, and one feature which had overcome a difficulty that the Author would probably meet with if he tried to use his dynamometer with large and fluctuating powers. The transmission dynamometer was more and more wanted, and if a satisfactory and simple one could be obtained it would be very much more frequently employed than at present. The one point that he thought was novel in the dynamometer was the use of the steel tape for securing motion to something that would indicate merely difference in torque. The fact that the other parts of the dynamometer were not novel was perhaps of no great importance, because there were so many features in the older instruments that might be successfully used with the Author's new element. It was certainly a point of much practical importance to be able by the looped steel tape arrangement, or in some cases by the very light and beautifully made cycle chains, to record the difference in power, either at the instrument or at some little distance from it, in the way that the Author had shown to be possible. Some of the forms of dynamometer that he had exhibited on the screen were very old and familiar forms, and although there were slight differences he thought that Mr. Courtney would be able to tell of the use for many years of certain forms of dynamometer by the Royal Agricultural Society, to some of which the new instruments shown by the Author bore considerable resemblance. He wished to ask the Author why he had used in his dynamometer a spring of such large diameter, and such a short spring on a machine that gave plenty of room for a spring of smaller diameter, of more truth, and of greater length. He thought that most of the members would not agree in what Professor Ayrton had said about measuring torque in foot-lbs., because engineers knew well what was meant, just as it was well known what was meant when persons spoke of so many knots; but with such mixtures of measures as "foot-lbs. per centimetre" there was no wonder that the Author should have made mistakes. Mr. Beaumont.

[1] Minutes of Proceedings Inst. C.E., vol. xcv. p. 1.

Prof. Smith. Prof. R. H. SMITH thought the mechanism described in the Paper most ingenious. In dealing with the design of the dynamometers proper the Author had referred to the advantage of a spiral spring coiled round the running shaft over a tangential spring; and had mentioned that the centrifugal force did not affect the spring coiled round the shaft because the spring was twisted. The stress on the section of the spring was not torsion. The twist of the spring as a whole was spoken of, but the stress itself was not torsional stress but bending stress; and he was doubtful whether centrifugal force had not a material influence upon the strain on the spring. He nevertheless fully agreed that this form of spring was by far the better kind to use in a dynamometer, and that centrifugal force effects were far less in that form than in any other. The horse-powers used in the experiments were extremely small, and even for a dynamometer of that size it was hardly fair to judge of the frictional efficiency of a machine from the measurements of very small forces. The smallness of those forces might be the cause of the immense difference between the two lines in *Fig. 7*, or the numbers in columns 6 and 7, Table III, which otherwise he could not understand. If all that energy was lost between the dynamometer shaft and the electro-dynamic action between the field-magnets and the armature, the efficiency of the whole arrangement was terribly low. The subject of the Paper was really the indication of the relative positions of two rotating shafts. He observed that the indicator was very massive. In his own dynamometers it was found that the indicator vibrated rapidly and in such a way as to show great sensitiveness and great freedom from frictional effects while running. That showed that in order to obtain true indications there must be a very light indicator. He could hardly imagine those two massive brass pulleys and the frames running backwards and forwards with anything like the speed of vibration that was really necessary to indicate the true variation of the driving moment that he had found over and over again to be actual. If those pulleys and the frames were made of aluminium no doubt the instrument would work better. The indicator was driven by an extremely flexible steel belt; and at a high speed any belt would surge. Although the surging was ordinarily diminished by increasing the tension of the belt it could not be wholly eliminated, and even under certain conditions an increase of tension increased the surging effect, which would be indicated upon the pulleys. It did not mean true variation of driving moment. The invention had two very ingenious parts,

viz., the use of the endless belt in two loops and the three-bar guides. Although the latter was extremely ingenious, he thought it was needlessly complicated to produce the effects desired. The same effect might be more simply attained in the manner shown in *Fig. 8.* But engineers found that with a solid guide-bar and crosshead a good fit could be obtained without spring contacts. There were two frictional effects in a dynamometer which ought to be distinguished from each other—there was the driving friction which hindered the deformation of the spring; and there was the friction in the indicating apparatus. In any good dynamometer the indicator itself was arranged independently of the driving forces transmitted. None of the friction caused by those driving forces would introduce frictional inefficiency in the indicator. This had an important bearing upon the calibration. He had found that during running the frictional hindrance to the straining of the spring was very small, and by static calibration, therefore, if the elasticity of the spring was measured in such a way as to avoid friction, a set of results would be obtained that was applicable to the running machine. This was easy by pulling the spring round by a rope running off in two opposite directions with two equal and opposite forces so as to produce no bending or total pressure on the shaft and the bearings. He thought it of great importance in the use of transmission dynamometers to place the instrument on the machine being indicated in such a way as to allow the machine to run under precisely the same conditions as those found in ordinary working. He therefore took off the ordinary driving-pulley and replaced it by a dynamometer pulley. The change of conditions involved in the use of most transmission dynamometers was, he thought, a serious interference with the actual working conditions, and threw doubt upon the applicability of the measurements. Prof. Smith.

Fig. 8.



Mr. W. G. Walker found the subject of the Paper particularly interesting, because so large a part of his work consisted in testing the efficiencies of various machines. During the last 12 months he had had occasion to test nearly one hundred different machines, chiefly of the smaller type, such as fans, pumps, and Mr. Walker.

Mr. Walker. the like. He had had, therefore, to consider the best means of measuring the power absorbed by the various machines, and had devised several forms of transmission dynamometers for the respective trials. The type he had chiefly used, and which he continued to use, was a calibrated electric motor. It was well known that the torque, in a series-wound motor, was proportional to the current, so that all that was necessary was to read off the number of amperes and take the number of revolutions. In that way the work was obtained at once. The beauty of the method was that the motor itself acted as a transmission dynamometer. When so many electric motors were being introduced into various engineering works, makers should, he thought, calibrate them, so that, by simply reading off the current and the number of revolutions, the work could be at once ascertained. With reference to the calibration of the dynamometer shown by the Author, it would be observed that it was calibrated when it was stationary. His experience showed that transmission dynamometers should certainly be calibrated when in motion. The apparatus was much more sensitive when in motion, and the apparent friction seemed less on the same principle as a high-speed governor.

Prof. Dalby. Prof. W. E. DALBY, in reply, ventured to submit that the two springs which Prof. Ayrton had referred to as applied to a dynamometer in such a way as to eliminate centrifugal force were not used for that purpose, but were introduced to eliminate vibrations to avoid the surging backwards and forwards of the index which would occur in that instrument, and also in other instruments with a single spring, if the load were variable. The test given in the Paper was not intended as a test of a dynamo, but was merely given as an illustration of how the instrument might be used. The dynamo that was tested was a very old one, and probably that would explain the wide distance apart of the curves to which reference had been made. With regard to the damping effect, he would again ask the members to bear in mind the difference between the two parts, the measuring part and the spring. The spring was not in any way new. The subject of the Paper was the means of measuring the angular displacement of the two ends of the spring. Any damping to be added would more properly be introduced between the ends of the spring, and not on the measuring mechanism. This, he thought, could easily be devised. The greatest speed at which the instrument had been run was about 600 revolutions per minute. With reference to the recording apparatus, he might say that he had drawn out an

arrangement for fitting it to the pulleys, so that a continuous automatic record could be obtained of the torque acting upon the shaft. The highest activity to which the instrument had been at present applied was $1\frac{1}{2}$ HP.; but if an instrument to measure 600 HP. was required he should be happy to apply it. The longest band that had been used was that he had shown on the screen about 10 feet from the shaft to the measuring instrument; it was a band about 40 feet long, and had run without trouble. The shaft was running at 500 revolutions per minute, so that the diameter of the pulleys would be about 4 inches or 5 inches. The speed, therefore, would not be great. He did not think there would be difficulty in running the band at a much greater speed if required. The bands were very thin and ran smoothly, without serious oscillation. In answer to Mr. Burstall, he might state that the problem was to measure the relative angular distortion of the spring. He had not set himself in any way to consider specially the form of spring or the way in which it was to be applied on the shaft. He took practically the existing arrangement and designed an apparatus to measure the angular displacement at the ends of the spring. To measure the torsion of a 2-inch shaft, the measuring pulleys would have to be of great diameter, but there would be no difficulty in making them large enough. There was no difficulty in punching bands accurately, and therefore no difficulty in making them apply to larger pulleys. He did not wish to defend the spring exhibited; it was no doubt a bad one, but it was on the instrument at the time as a trial spring, and as the dynamometers had to be shown there was no time to alter it. The instrument was badly out of truth, as could be seen by the way in which the machine had been strutted up to avoid excessive vibration. The spring was of large diameter in that particular case for a special reason—to enable stops to be arranged between the shafts and the pulley. It was necessary that there should be stops to limit the motion of the springs, because in the starting of any instrument the torque was very much greater than when the instrument was running, and suddenly to throw the torque on the spring would probably strain it beyond its proper limit; consequently, stops had to be arranged on the dynamometer to limit the angular displacement within the limits of the maximum range of the spring. With reference to Prof. Smith's remarks on centrifugal forces, he had not intended to convey in the Paper that the effect of centrifugal force was entirely absent. His meaning was that it only affected the spring in a secondary way. When the spring was arranged in Prof. Dalby.

Prof. Dalby a plane at right angles to the shaft it was subject to centrifugal force as a whole, and the error from this cause would be greater than if it were arranged round the shaft. He wished to point out that the loss shown between the dynamo shaft and the terminals of the machine included all the interior losses. The machine appeared to Prof. Smith too insensitive in the pulleys—that there was too much weight in them. Many other speakers had thought it too sensitive, so that it was difficult to know how to answer the remark. By tightening the constraining spring the forces acting on the pulleys to keep them in the loops could be increased to any desired amount without causing any increase of friction. The result was that they followed the loops quickly and accurately. The pulleys could be made of aluminium to lighten them, but he did not think they could be made much smaller to be run successfully. It was about the smallest pulley that could be used in order to keep the joint of the band from breaking. With regard to the frame sketched by Prof. Smith, no matter what arrangement was made to constrain the motion of the frames, there must be five points of constraint. If there were more, there would be a redundant number, but a single degree of freedom could not be obtained with less. In Prof. Smith's sketch he had only given a cross-section. If he had added the plan, he thought it would be a more complex frame than the one described in the Paper—it would certainly be heavier. The frames described and exhibited could be very easily made—a boy could file them up. To make an ordinary slide would require a fitter at the Amalgamated Society's maximum wages. He thought that it would be found that to make frames in the way he had suggested would cost much less than if they were made with an ordinary slide.

Correspondence.

Prof. Ewing. Professor J. A. Ewing had enjoyed the advantage of seeing the Author develop his ideas, the dynamometer having been designed and constructed while the Author was still demonstrator in the engineering laboratory at Cambridge. The idea of exhibiting the relative displacement of two parts of the revolving system by means of an endless band was, he believed, a new departure in dynamometry, and it had been well carried out. The Author was especially to be complimented on his design of the kinematic slide in which the guide-pulleys worked. The principle of

furnishing just the right number of points of contact to give the desired constraint was one which did not find nearly so much application by engineers as it deserved. Thanks to the application of that principle in the present case, the Author's apparatus worked very smoothly and with conspicuous freedom from friction. It had an open scale, and was sensitive to small changes of load. So long as the load was not liable to sudden fluctuations, that was an advantage, and the Author's dynamometer was found to work exceedingly well when the load was constant or at least fairly steady. It was not so well adapted for a rapidly fluctuating load on account of the absence of anything equivalent to a dash-pot between the fixed and the loose pulleys. The Author was to be congratulated on having produced an instrument which might be of considerable service, and which presented several admirable features as a piece of mechanical design. Prof. Ewing.

The Rev. Frederick J. Jervis-Smith had from time to time for some years worked on dynamometric measurement, and considered that the Author was doing an excellent service to engineers and students of electricity, by bringing before them a machine which gave numerical values of dynamometric tests which were easily observed by means of a pointer moving over a divided scale. He had used spiral springs as a torsional shaft in 1881,[1] but many experiments with such springs had led him to use two solenoidal springs instead of one, the ends being attached to a block keyed on to the shaft, and to the boss of the belt pulley, symmetrically at 180° apart, so that they formed a screw of double thread when in position on the shaft; the symmetrical disposition of the springs contributed somewhat to accurate balancing. The differential method of moving an index or pointer, indicating the torsional angle, devised by the Author, was in theory excellent, and it appeared to have proved itself efficient in practice. In a model of a torsional dynamometer which he had exhibited at the Royal Society in May 1894, an epicyclic differential gear was used to indicate the torsional angle.[2] He used the epicyclic gear to avoid any slip and consequent error; only two elements of the apparatus Rev. F. J. Jervis-Smith.

[1] "Work-Measuring Machines." F. J.-S. Spon. Tract 8vo. vol. 409. Library Inst. C.E.

[2] A Torsion Ergometer, and Differential Gear for Reading the Torsional Angle of a Shaft or Solenoidal Spring Coil, used in the Dynamometric Testing of Screw Propellers; and a Mechanical Integrator. Tract 8vo. vol. 575. Lib. Inst. C.E.

Rev. F. J. Jervis-Smith.

were displaced in order to give a direct scale reading of the torsional angle. The Author was to be congratulated on his introduction of the kinematic slide, as it had the great advantage of giving an excellent and reliable result, with but little expenditure of labour upon fitting. He would suggest that as the index moved in a right line over the scale, a record might be easily made on a revolving cylinder driven from the shaft; such a record was in many cases far more valuable than any reading given by a continuous integrator—after the lapse of a known period of time—since it showed by the form of the trace the manner in which the integral was being formed at each instant.

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11 January, 1898.

Sir JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S., President, in the Chair.

Sir JOHN WOLFE BARRY, K.C.B., President, said it was his painful duty to communicate to the members the death of their Past-President and dear friend, Sir Charles Hutton Gregory, K.C.M.G., who passed away on the 10th inst. at the ripe age of eighty years. Sir Charles Hutton Gregory had been for sixty years connected with the Institution. He served for twenty years on the Council, and had occupied in a distinguished manner the post of President. Since the date of his Presidency he had always shown the same interest in the welfare of the Institution which he had done while he was connected with it as a member of the Council and as President. His career was contemporaneous with the introduction of railways, and he had occupied a very important position in the early days of railway enterprise. His name in that respect would be *inter alia* familiar to everybody, as the introducer of the semaphore system of signalling trains, which had been of such great utility to the whole of the railway world. Apart from work at home, Sir Charles Hutton Gregory was a trusted servant of many ministries in connection with Colonial work, and always occupied the highest position in that branch of engineering. Sir Charles Hutton Gregory was not only a distinguished engineer, but he was an ornament to his profession. He was an honourable and an upright man, and the firm friend of many members, who could always rely upon his friendship. He thought there were two classes of members of the Institution, or two classes of persons connected with it, who would have great reason to regret the loss of Sir Charles Hutton Gregory, for he was always a most kind and sympathizing friend to young engineers, and did all he could to forward their interests. His heart was also ever open to the cry of any distress from any of the less fortunate members of his profession, and he took the liveliest interest in all matters connected with the administration of the Benevolent Fund. All who knew him would feel that

the Institution was much the poorer by the loss of Sir Charles Hutton Gregory, and his memory would be cherished by its members for many years as one of the kindest, most honourable and distinguished engineers of the present century. He begged to move "That the members of the Institution deeply regret the death of Sir Charles Hutton Gregory, K.C.M.G., Past-President, whose association with the Institution during a period of almost sixty years has been marked by unremitting interest in its welfare."

The resolution was carried unanimously.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

JOHN GRAHAM. | ROBERT LOWTHIAN TREVITHICK.

And that the following Candidates had been admitted as

Students.

FREDERICK ARTHUR BARNES.
PERCY LLOYD BOWERS.
ERIC ANDREW CUTHELL.
JAMES WEIR FRENCH.
WILLIAM TOLMÉ MACCALL.
LEONARD REDMAYNE.
EDWARD THEODOR TOMLINSON.

The Candidates balloted for and duly elected were: as

Members.

ROBERT TWENTYMAN NAPIER. | ROBERT STIRLING.

Associate Members.

CHARLES REVILL BELLAMY.
FREDERICK GEORGE COCKEY.
ALEXANDER JAMES NEELY, B.A.I. (*Dublin.*)
WILLIAM TODD PICKERING.
JOSEPH BOWMAN WILSON.

Associates.

Right Hon. ANDREW GRAHAM MURRAY, Q.C., M.P.
PHILIP JOHN JOSEPH RADCLIFFE, *Captain* R.E.

(*Paper No. 3075.*)

"The Machinery used in the Manufacture of Cordite."

By Edward William Anderson, Assoc. M. Inst. C.E.

The Committee appointed by her Majesty's Government to produce a smokeless explosive for military and naval purposes, consisting of Sir Frederick Abel, Bart., K.C.B., Hon. M. Inst. C.E., Chairman, Professor James Dewar, and Dr. August Dupré, with Captain Thomson as Secretary, having practically settled the composition as well as the shape in which it was to be used, requested Sir William Anderson, K.C.B., Vice-President Inst. C.E., to assist them by designing suitable machinery for its commercial production. He accepted the invitation, and, assisted by the Author, had made some progress in the matter, when in 1889 he was appointed to his present office as Director General of the Ordnance Factories. The Author then took up the subject alone, and has since kept in close touch with it. He now proposes to place on record a description of the machinery at present in general use; and, so far as they are interesting or instructive, the steps by which the various designs or processes were arrived at. Whilst many ideas and suggestions were due to Sir William Anderson and the Author, a considerable portion were likewise due to the Explosives Committee and their staff in the earlier stages, and later to the officers and staff in charge of the manufacturing establishment at Waltham Abbey. The names of Dr. Kellner, Chemist to the War Office, Major Nathan, and Mr. C. Frewen Jenkin, Assoc. M. Inst. C.E., may be specially mentioned in this connection.

Cordite, as now made, consists of 58 parts of nitro-glycerine, 37 parts of gun-cotton, 5 parts of mineral jelly, and 20·83 parts of acetone, which is merely a solvent and is driven off in the drying process, so forming no part of the ultimate product. These materials are made by processes which it is outside the province of this Paper to describe. The form in which the explosive is for the most part produced, namely, that of solid cords or strings of various diameters, was determined by the

Explosives Committee as the most suitable, the sizes being arranged to suit the various weapons for which the explosive was to be used. Thus, for example, for the 0·303-inch Lee-Metford rifle the nominal diameter of the cords is 0·0375 inch, and for the 12-inch naval gun it is 0·5 inch. The cords are cut into pieces of suitable length and are bundled together in sufficient number to form the requisite charge for the cartridge. The nominal sizes generally made are 0·03 inch, 0·0375 inch, 0·05 inch, 0·075 inch, 0·1 inch, 0·15 inch, 0·2 inch, 0·3 inch, 0·4 inch, 0·5 inch in diameter; but they are not usually described by these figures, but by those obtained by multiplying them by 100. Thus 0·0375 inch diameter is called $3\frac{3}{4}$, and 0·3 inch diameter is called 30. The length in inches is usually given also, as the denominator of a fraction of which the numerator is the size. Thus $\frac{20}{14}$ signifies cordite 0·2 inch in diameter cut into pieces nominally 14 inches long. The uniformity of diameter is an important factor in the production of uniform ballistics, upon which good shooting so largely depends; and the Government specification provides for only a small permissible variation in this respect, but somewhat more latitude is given in regard to the length. For use in blank cartridges it is found that the best form of the explosive is that of thin circular wafers, made by cutting round cord into transverse slices.

The process described in the Paper, under the seven sections into which it may be divided, is that carried on at the Government factories of Waltham Abbey and Woolwich Arsenal; it is probable that private manufacturers conduct some of their operations in a slightly different manner.

Mixing the Gun-Cotton and Nitro Glycerine.

This process is always performed by hand. The gun-cotton is produced in the factory in the form of finely divided pulp, which is compressed with slight pressure into cylinders about 6 inches long and 3 inches in diameter, and in this state is dried; the reason for so compressing it being that the production of dust, which forms a dangerous element in the drying process, as it so easily takes fire, is very much lessened. Formerly the dry gun-cotton was removed to a store; now the stoves are allowed to cool, and are used as stores, so as to avoid both the danger and labour attached to moving. After drying, the cylinders are weighed out into brass-lined wooden boxes, provided with suitable covers, which are then conveyed to the nitro-glycerine factory, where the proper

amount of nitro-glycerine is poured into them, and incorporated by hand till a proper mixture or solution has taken place. The boxes are then covered and are removed to the paste store to wait the next stage of the process. Until a few years ago it was the custom to store a certain quantity of nitro-glycerine in a special building set apart for the purpose, the object having been to give time for the complete separation of the washing water, and there to mix it with the gun-cotton; but since the explosion in this building in May, 1894, no storage is permitted; and the mixing is performed in the building where the last stage of the manufacture of the nitro-glycerine is carried on, by which means the only free nitro-glycerine about is that in actual process of manufacture. The danger of explosion is greatly diminished by this arrangement, for it is found that mixing the two explosive substances results in a comparatively inert compound, which, though highly inflammable, is not easy to explode, and may be safely transported from place to place. If therefore any storage is required, it takes the form of this mixture, instead of the much more sensitive and dangerous nitro-glycerine and gun-cotton. This fact also enables the factory to be divided if required, keeping the nitro-glycerine section completely by itself. The gun-cotton may then be sent to the nitro-glycerine section, and be returned as "paste," as it is usually termed. This method was adopted by the Government when the nitro-glycerine factory was wrecked in the explosion referred to, and the "paste" was made of Government gun-cotton sent in the wet state to private nitro-glycerine factories, whence the mixture was returned to be worked into cordite at Waltham.

Incorporation and Introduction of the Acetone and Mineral Jelly.

This operation is performed by the aid of machines, the function of which is to thoroughly mix all the ingredients so as to yield a homogeneous mass of uniform quality. The system universally used, so far as the Author is aware, is that of Messrs. Werner, Pfleiderer and Perkins, whose machines, originally designed for mixing and kneading various materials, have proved, with slight modification, to be exactly suited to this purpose. The Author is indebted to Mr. Paul Pfleiderer for the following description of the machines.

In a trough of double semi-cylindrical shape, Figs. 1, Plate 2, with a prismatic upward extension, two sets of blades revolve interdependently at different speeds about axes corresponding

with those of the two semi-cylinders. The blades touch and intersect each other's charge, but their orbits never intersect, and the blades do not touch—an important feature where the mass is explosive. The top being raised, the blades with the wheels fixed on their axles can readily be lifted off also for periodical cleaning. For ordinary cleaning and for discharging the finished mass after each operation, the trough with its revolving wheels and blades is tilted in its entirety, as shown by dotted outline. The direction in which the blades revolve, either against or from each other, is reversed by a simple friction clutch. It consists of two loose pulleys with a fixed disk between them. The pulleys are driven, one by an open, the other by a crossed belt. By a handwheel the attendant forces the disk into or out of grip with either pulley. The arrangement is such that, by screwing the handwheel in the direction in which he wishes the machines to be driven, the attendant engages the pulley which revolves in that sense; while when the machine is working in either direction, the handwheel is revolving in the same direction, and by stopping it the attendant stops the machine. The disk is secured on the shaft of the machine by a feather, over which it fits loosely, the loose pulley runs on a sleeve, or elongated boss of the disk, screwed at its end, and the handwheel forms the nut for this screw. The boss of the handwheel on the front side and the boss of the back pulley on the back, are held at a maximum distance by two stops or set collars fixed to the shaft, between the faces of which set collars their axial movements are confined. A pair of rings connected by pins passing loosely through the disk keep the two pulleys at a constant distance, pushing the one out of grip with the disk before the other can possibly be engaged. Both the mixing and the discharging operations are facilitated by reversing the direction in which the mixers work. The peculiar shape and setting of the blades are the outcome of many years of experiment. Adapting them to a large number of materials to be treated has finally produced the best shapes for efficiency of working, and facility of emptying and cleaning. Many of the present shapes may recall ships' propellers, but they have all been derived by evolution from an inclined plane with elliptical contours.

The materials to be incorporated are poured into the top, or hopper, of the trough; they fall between the revolving blades, and are squeezed and moulded into more or less perfect cylinders, which, as they emerge from their moulds (the semi-cylinders of which the bottom part is composed), become rapidly distorted,

intersected and displaced. A lively interchange of particles sets in, which in their paths are rubbed and pressed against and into one another in all directions. The shapes of the blades are so chosen, that together with their differential speeds, they effectually prevent the formation of "dead centres" or "cores." Their ever-varying relative angles and positions prevent a frequent repetition of the same phase or relative state, and thereby of monotony in the mixing movements, in a much higher degree than is often obtained by more complicated shapes, which are difficult to clean, and highly scientific kinematic motions which are liable to get out of order. As the material under operation itself plays a most important part in bringing about the desired mixing and kneading action, it is essential that the shape of the blade should be in each case carefully adapted to the nature of the mass to be treated; and it must depend largely on the cohesiveness of the latter, and on its adhesive qualities in regard to the metal of which the mixer consists. Various sizes of these machines have been used. The original experiments were conducted with machines worked by hand, and holding only 1 lb. or 2 lbs. of explosive; but subsequently, when the manufacture was commenced on a large scale, the size for the most part employed was that capable of holding about 75 lbs.; and now a machine to contain 150 lbs. has been generally adopted.

In the process of incorporation the paste is first put into the machine and the acetone is poured on it. The cover is put on in order to prevent evaporation of the acetone as much as possible, and the machine is started. After 3½ hours the mineral jelly, which has been previously well strained, is added; when the process is continued for 3½ hours more, so that the whole period of incorporation is 7 hours. The speed of the large sized machine is about 31 revolutions per minute. At the close of the operation the explosive is emptied into suitable covered boxes, and is taken straight to the presses, as it is important to use it promptly before the acetone can evaporate. About three charges can be incorporated by each machine in 24 hours, or sixteen charges per working week. The bottom of the machines is water-jacketed to prevent undue heating during incorporation, and the connections with the water-main and drain are made by flexible pipes, so that the machine may be tilted easily without breaking any joints. A drenching-pipe is placed over each machine, so that, should any accident take place, the charges in all the machines can be quickly drowned. Accidents, however, never occur, and the precaution is, though wise, practically superfluous.

A curious source of danger was discovered in the fact that frictional electricity is developed by the belts of these machines, and sparks could be taken from them. The remedy is, however, simple; it is only necessary to connect the machines electrically to earth, and to place a brush collector near the belt, also earthed, when all cause for anxiety is removed.

Pressing.

The material having been properly incorporated, and having a consistency about equal to that of stiff dough, is ready for conversion into the form of cord. There appears to be but one way in which this can be done, namely by forcing it through a die of the proper size and shape; and, accordingly, all the machinery is designed to fulfil this end. The obvious plan is to use a cylinder of suitable size, having a die of the required dimensions at the end, and a close-fitting plunger capable of being forced into it; so that if the cylinder is filled with the dough and the plunger is pressed in, the dough will be forced out through the die in the shape of the hole through it. In this particular case the cord is invariably circular in section, and is usually solid, though for some purposes, such as for primers, it takes the form of a tube. The original laboratory apparatus used in the experiments at Woolwich was, like this, of small dimensions and of steel; so that it could be easily used in conjunction with a small hand screw-press. Later, hydraulic presses were employed, which could deal with larger quantities, and so enable experiments to be tried on heavy guns, requiring larger sizes and a greater quantity of the cordite. Soon, however, it became necessary to make a press of commercial dimensions, and one of a size suitable for making rifle cordite was projected.

Experiments were first tried to ascertain the pressure necessary to force the dough through a hole of given size, and at a given speed, and upon the results of these the design was based. As the pressure necessary was found to be high, it was decided to make a hydraulic press; but, in view of the subsequent operation which the cord would have to undergo, it was considered that the regulation of the pressing should be effected by positive gearing such as a screw, so that the motion of the plunger, and consequently the rate of emission of the cord, should be uniform. Accordingly a screw was inserted between the hydraulic cylinder and the pressing chamber with a nut and thrust-bearing that

could be rotated by suitable gearing, by which means any tendency to uneven motion might be regulated and corrected.

The pressing cylinder was made 2 inches in diameter with a stroke of 6 inches, to hold about 1 lb. of the explosive, and the die was 0·0375 inch in diameter. The axis of the cylinder was horizontal in this first press, and it was erected in the temporary experimental shed at Woolwich Arsenal. It was soon found that the combined hydraulic cylinder and screw was not a success; but it fortunately happened that, probably owing to recent modification in the composition and plasticity of the explosive, the pressure required, as experimentally obtained, was considerably in excess of that now proved to be needful; so that the hydraulic cylinder could be dispensed with and the screw alone used—a plan which answered well. This press was eventually removed to Waltham, where it is still used.

There were, however, still difficulties to be overcome. On two occasions, when the Author was present, the emission of the cord was arrested by an obstruction in the die; but the press continued working, and, before it could be stopped, the pressure in the cylinder was increased to such an extent that it dislodged the obstruction; and thereupon, owing to the elasticity of the explosive, the cord was shot out for an instant at great speed, so that the friction of its passage through the die was sufficient to ignite it. Fortunately it did not strike back through the die on either occasion and fire the charge in the cylinder, or the results might have been disastrous. This showed that cordite was a very safe explosive to manufacture—a fact that has often been demonstrated since; but that it was advisable to provide some means for preventing such excess of pressure. The difficulty was met by a suggestion of Dr. Kellner, who proposed a strainer between the die and the chamber of the cylinder—a plan which proved successful. The arrangement consisted of a steel plate $\frac{3}{16}$ inch thick, pierced with a number of $\frac{1}{4}$-inch holes, fixed in the bottom of the cylinder and covered on the cylinder side with a disk of iron-wire gauze; under it was a shallow conical recess in the cylinder cover, in the apex of which the die was placed. It was found that a considerable quantity of impurity, imperfectly dissolved gun-cotton, &c., was caught by these strainers, and they required frequent cleaning; so the pressing cylinders were constructed in such a way that they could be easily removed and fresh gauze disks could be inserted as required. This system is still in use, and although, owing to improvements in the details of manufacture, a very much smaller amount of

impurity reaches the material than formerly, there is even now sufficient to render the strainer necessary; as it must be remembered that foreign substances not only constitute a source of danger, but they also interfere with the quality and regularity of the product. The disks, after use, are placed in a special receptacle, and are taken away at intervals for cleaning. The renewal of a disk is found to be desirable after about six charges in the smaller and three charges in the larger presses. The cleaning is performed by soaking in acetone till all the cordite is dissolved, and then brushing with a scrubbing-brush.

Experiments had previously been made chiefly with rifles, and only to a limited extent with large guns; but as it became necessary to prosecute trials to a greater extent in the latter direction, it was decided to design a larger press more suitable for the quantity of cordite that would be required—a duty which was undertaken by the Author. In this new design the point was raised whether it would not be possible to render the process of manufacture continuous instead of the reciprocating system involved by a press, which, of course, necessarily wasted a certain amount of time in the return stroke and in refilling or charging the pressing cylinder. After much thought had been bestowed on the subject, no plan was arrived at that gave any promise of success, and it was decided to adhere to the original method. A second point was, whether multiple dies could be used with advantage, and experiments were made in this direction, but the results were not satisfactory. It may, however, be mentioned that eventually multiple dies were successfully introduced, and are at present used to a considerable extent, the difficulties originally found with them having been surmounted. A third point was the old question of screw *versus* direct hydraulic action, and, in view of the subsequent processes, the screw again carried the day on account of the uniformity of its action. The result was the machine now usually called the Intermediate press, Fig. 2, Plate 2. Comparing it with the former one, the first point of difference is that it was vertical instead of horizontal—a plan which proved a decided improvement, and which has been invariably followed since. The pressing-cylinder was made 6 inches in diameter, and the plunger stroke was nominally 12 inches, so that the charge of explosive was equivalent to about 10½ lbs. when dry. The plunger was attached to a steel cross-head, on the upper end of which the screw was forged, and which was guided in a cast-iron framework; the nut and thrust-block were carried by a bearing in the upper cross-piece of this frame, and were revolved by suitable gearing. In order to shorten

as far as possible the time of the cycle of operations, a quick-return motion was provided, by means of open and crossed belts running on different-sized pulleys on the driving-shaft; and a simple arrangement of belt-striking apparatus was contrived, so that, when the plunger had reached the end of the downward or pressing stroke, the gear was automatically reversed and the quick return proceeded without any intervention of the attendant. As soon as the return stroke was completed, the gear was automatically stopped in a similar manner, and remained so until started by the attendant for a fresh pressing stroke.

The pressing-cylinder was necessarily heavy, and its removal for charging was not very easy, so that a new method was introduced which gave the press several important advantages. A hydraulic cylinder was attached to the top of the two main steel columns of the press, and a cast-iron ram proceeding downwards from it was attached to the cast-iron frame already alluded to, and which was made capable of sliding up and down on the columns between fixed stops at the top and bottom. The annulus formed between the ram and the piston of the cylinder was sufficient to allow of the water, supplied from the ordinary waterworks mains in the factory, exerting sufficient pressure to raise the whole frame, with the screw, nut, gearing and plunger, bodily about 12 inches. The connection with the driving gear was preserved by means of a vertical shaft with a long feather in it, upon which the driving pinion of the gearing on the sliding frame could travel. When therefore the return stroke was ended, or even shortly before that, and pressure water was turned on to the annulus of the cylinder, the whole framework was quickly raised, leaving a clear space between the plunger and the cylinder, into which a light brass cylinder filled with the explosive material was at once introduced. On reversing the hydraulic valve, the water was turned on to the upper side of the cylinder, and quickly forced the charge out of the so-called charging-cylinder into the pressing-cylinder, until the frame came down to the bottom stops; the gear was then started and the pressing commenced.

The hydraulic slide-valve had a non-return valve in connection with the upper end of the cylinder, which could be automatically opened by the valve lever when the water from the top of the cylinder was required to be exhausted; so that, when the frame was down ready for pressing to commence, this valve was allowed to close, and thus the water in the cylinder was imprisoned. The result was that the upward thrust of the press was taken upon this water; and, by attaching a safety-valve to the upper

end of the cylinder loaded to a given pressure, if any undue stress was put upon the pressing plunger through such a cause as the obstruction of the die, the safety-valve would relieve the plunger by allowing the whole frame to rise. This therefore constituted a safety device, and prevented any possibility of an accident such as that recorded in connection with the first press. But the arrangement had yet another advantage, for by attaching a pressure-gauge to the upper end of the cylinder, at any moment the actual pressure on the explosive could be seen, the necessary allowances being made for relative areas of cylinders, friction, &c. Although the absolute pressure is of no great importance, the uniformity of that pressure throughout the charge, and for successive charges under similar conditions, gives a very good indication of the uniformity of the incorporated material and the correctness of its consistency, thereby assisting in no small degree in securing uniformity in the finished product—a matter of the highest importance.

In order to simplify the mechanical arrangements, provision was made for one speed only for the advance of the screw; but as the speed of emission of the cord was required to be the same for most of the sizes made, it was arranged to use a different size of cylinder for each size of cord, the diameter being calculated to give the necessary speed of emission. Thus, for instance, the 6-inch cylinder was used for cordite of 0·3 inch diameter, and a 4-inch one for cordite of 0·2 inch diameter.

This press was set up at Woolwich, and worked well. It was subsequently sent to Waltham Abbey, where it is still in regular use. The only material alteration that has been made is, that the charging cylinder is now fixed, and is provided with a side-feeding hopper; so that, after withdrawal of the plunger by the hydraulic arrangement, a slide at the bottom of the hopper being withdrawn, the pressing-cylinder and about 9 inches of the charging-cylinder are at once filled with loose incorporated material. The descent of the plunger compresses this into the pressing-cylinder, and then the screw begins to work as before. The cylinder is now seldom or never changed, because, as multiple dies have been adopted, if cordite 0·2 inch diameter is to be made, a double die of this size is put into the 6-inch cylinder, and produces the same effect as using a single die with a 4-inch cylinder, with the important difference that the output of the press is doubled. In addition, the speed of the press has been increased by an alteration to the gearing, so that, without decreasing the speed of emission, a treble die of 0·2 inch diameter, or a double one

of 0·3 inch diameter, can now be used with a 6-inch cylinder; and thus a further increase in output has been obtained. The strainers in the bottom of the cylinders are removed for cleaning by unscrewing a large plug provided with handles, containing the gauze and the die; which, after changing the gauze, is replaced. This plug was at first made with an interrupted screw, like a breech-block, for accelerating this process; but a plain screw was eventually found to answer better.

This press, having been successfully started, and the good qualities of the new explosive having been established, the erection of a permanent factory on a large scale at Waltham Abbey was decided upon, and this at once made it necessary to prepare a design for the presses for making the rifle cordite, of which many would be required. Two or three schemes were prepared by the Author, of which one was finally adopted, and which, with slight alterations and improvements suggested by subsequent experience, is that still in use by the Government, and at most, if not all, the private factories. Regulation of the speed was of even greater importance for rifle cordite than for the larger sizes, and thus a screw press was almost imperative. The vertical arrangement, which worked so well in the intermediate press, was at once decided upon; and although the question of multiple dies was again mooted, it was abandoned; and they have never yet been adopted in making this size. The press, Fig. 3, Plate 2, consisted of a cast-iron framework fixed to the floor, having a cross-piece in which a recess was formed for holding the pressing-cylinder, designed in such a way that it can be taken in and out easily, and when in can be locked in position so as to be kept truly concentric with the plunger. Each press had two cylinders, so that while one was in use in the press, the other was being filled with the dough, and no time was lost between successive charges. The screw was operated by a worm and worm-wheel, which, as in the former press, revolved the nut, and so advanced the screw. The slow motion for pressing and the quick return were given by pulleys of different diameters on the worm shaft, driven by open and crossed belts. Striking gear for the belts, of a similar design to that in the larger press, was again used and produced the same effect. Inasmuch as the cylinders, being small, can easily be removed for filling, no hydraulic arrangement was required; but, as the safety device and pressure indicator were even more important in this press than in the other, the following method was devised. The steel screw terminated in a cross-head, which was bored out on its under side, forming a short cylinder, and the

top of the plunger rod was expanded to form a piston fitting this cylinder, and packed with a U leather. The cylinder having been filled with liquid, the pressure of the screw was transmitted to the plunger through the medium of that liquid; and therefore, a pressure-gauge and safety-valve having been attached so as to communicate with the liquid, the desired result was obtained. For making up leakage due to possible blowing off from the safety-valve or otherwise, a small hand-pump and tank were fixed to the cylinder. An additional safeguard has been since added to this press, by means of which, if the pressure in the buffer cylinder (as it may be called) becomes excessive, the press is automatically stopped. It consists of a small hydraulic cylinder and plunger, connected by means of a suitable weighted lever and bell-crank, with the belt striking gear; and, by means of a flexible copper pipe, with the buffer cylinder. Thus, on the pressure rising abnormally, the plunger is forced out, overcoming the resistance due to the weighted lever, and moves over the belt striking bar by means of the bell-crank, so stopping the press. It may be mentioned that the last new design of the intermediate press has also had a similar arrangement added to it.

Since the first presses of this type were made, the improvements have been altogether in small details. The speed of emission of the cord, which was originally fixed at 100 feet per minute, has now been increased to about 376 feet per minute, partly by increasing the size of the pressing-cylinder, and partly by the speed of the gear. The cylinders at present used have a diameter of 2⅝ inches, and a nominal plunger-stroke of 6 inches. The buffer cylinder was originally made 4 inches in diameter, and oil was the liquid used to fill it; but in the more recent presses the buffer has been increased to 6 inches in diameter, in order to keep the pressure lower, which is found to give less trouble from leakage. Moreover water has been substituted for oil, because, should any leak out and reach the explosive, it does no harm, whereas oil is objectionable.

With these two types of presses the Waltham Abbey factory commenced to work. Shortly afterwards, Mr. C. Frewen Jenkin was appointed mechanical engineer to the establishment, and, guided by the experience which was continually being gained, he introduced various new designs in connection with the manufacture. One of the first was a new press larger than any yet made. No new principle of action was involved in its arrangement, and it may be generally described as a large rifle press, with the safety buffer lengthened and modified, so as to act as a

hydraulic raising-and-lowering apparatus, after the manner of the intermediate press, in addition to its other functions. The connections to the hydraulic valve for controlling these motions were necessarily of a flexible type, as the cylinder shifted its position in accordance with the motion of the screw. The pressing-cylinder was in this case 8 inches in diameter with a nominal plunger-stroke of 12 inches, and the quantity of explosive dealt with per charge was equivalent to about 21 lbs. when dry. The water for working the hydraulic cylinders of the intermediate and large presses was obtained at Waltham from the mains of the East London Water Company, which was supplied at a higher pressure than that available at Woolwich; so that no special pumping plant was required. The next step was a simplification of the pressing machinery for the large sizes of cordite, by departing from gear-driven screws and substituting an ordinary hydraulic press. Fig. 4, Plate 2, illustrates the arrangement as designed at Waltham and made at Woolwich Arsenal. The Waltham press is of ordinary type, constructed to work with the available water-works pressure of about 135 lbs. per square inch, and capable of taking a pressing-cylinder 8 inches diameter by about 16½ inches stroke. The ram is 22½ inches diameter, and has projecting from its top four short steel columns surmounted by a cast-iron plate, the whole thus forming a kind of stool on the top of the ram, upon which the pressing-cylinder is carried in such a way that it can be easily taken in and out of the press. The pressing plunger is fixed to the top crosshead casting. The cord is emitted at the bottom of the cylinder as usual, and passes away between the short supporting columns.

It will be seen that this press is much simpler than the screw press, and it would appear that the safety precautions introduced into the screw press are of necessity present in the hydraulic press, as well as the means of knowing the pressure at all times. It is nevertheless a fact, though, perhaps, one difficult of explanation, that, as far as the Author is aware, all accidents that have happened in pressing cordite have been in connection with direct-acting hydraulic presses, and he does not recall any instances of such an occurrence with a screw press, except those of minor importance recorded in describing the original imperfect machine. It is true that none of the accidents have been serious, and they have only served to show the comparative safety of the manufacture; but it seems reasonable to suppose that they would never happen were screw presses exclusively used. It would seem that speed had an effect on the liability to accident; and

that, if the press is allowed to work too fast, heating is set up either by friction or, as has been suggested, possibly by sudden compression of the air in the interstices of the dough, sufficient heat being generated to ignite the mass locally and cause explosions of varying degrees of violence; a curious circumstance being that only a small part of the charge ever explodes, and hence the damage is never very great.

In consequence of this state of things the authorities at Waltham enclose the large direct-acting presses in mantlets, and operate them from the outside, so that the effect of a possible explosion may be confined to the machine itself. The screw presses are not protected in any way. The experience at Waltham has also demonstrated clearly the bad effect of irregular motion on the resulting cordite, as it happens that the water-pressure in the mains is not by any means steady, the result being that the cords made by the direct-acting presses are liable to be of irregular diameter; because the size is considerably affected by the speed of emission, which will necessarily vary if the pressure varies, the rule being that the greater the speed the smaller the diameter of the cord. Hence steps are being taken to obtain a perfectly steady source of supply, when no doubt the result will be satisfactory.

These hydraulic presses are arranged so that the cylinders can be taken out and filled in any convenient place; and, to save time, each press has two cylinders, so that one is being filled while the other is in the press. A new design of intermediate press has just been made, in which the cylinders are removable by means of a small crane, and it is therefore somewhat similar to the rifle press in manner of working; but the arrangement of the parts is more like that of the original intermediate press.

Particulars of output, &c., of the different presses are given in the Table on p. 83.

Filling the Cylinders.—It was originally thought that it would be very important to consolidate the material well before pressing, so as to get rid of any air that might lodge in the interstices, and which might prove detrimental to the finished cordite. With this object, in the early experiments two pug-mills were made, in which the loose incorporated dough was placed, being forced out as a homogeneous mass into the press cylinder, which was attached for the purpose to the delivery nozzle of the mill. When full the cylinder was slightly slacked, the dough was cut through with a wire, and the cylinder was removed to the press, while another one was attached to the pug-mill in its place. The results, however, were not satisfactory, and the system was abandoned in favour

Particulars and Outputs of the Cordite Presses used at Waltham Abbey.

Description of Press.	Size of Pressing Cylinder.	Working Stroke.	Nominal Size of Cordite.	Actual Minimum Diameter allowed (dry).	Actual Maximum Diameter allowed (dry).	Ordinary Size of Die used (Subject to Variation).	Number of Dies used.	Approximate Weight of each Charge in finished Cordite.	Approximate Speed of Emission of Cordite.	Average Pressure on Safety Buffer.	Size of Safety Buffer.	Corresponding calculated Pressure in pressing Cylinder (neglecting Friction.)	Output per Day of Twenty-four Hours per Press in Three Shifts.	Output per Press per working Week.
	Inches Diameter.	Inches.		Inch Diameter.	Inch Diameter.	Inch Diameter.		Lbs.	Feet per Minute.	Lbs. per Sq. Inch.	Inches Diam.	Lbs. per Sq. Inch.	Lbs.	Lbs.
Small . . .	$2\frac{5}{8}$	$5\frac{1}{2}$	3	0·024	0·028	0·030	1	1	603	1,250	4	2,910	164	852
,, . . .	$2\frac{5}{8}$	$5\frac{1}{2}$	$3\frac{3}{4}$	0·030	0·034	0·038	1	1	376	1,300	4	3,200	164	852
,, . . .	$2\frac{5}{8}$	$5\frac{1}{2}$	5	0·042	0·046	0·052	1	1	360	1,050	4	2,440	180	935
Intermediate .	4	$11\frac{1}{2}$	5	0·042	0·046	0·052	3	5	300	600	8	2,400	640	3,320
,, .	4	$11\frac{1}{2}$	10	0·080	0·088	0·102	2	5	117	450	8	1,800	640	3,320
,, .	6	$11\frac{1}{2}$	15	0·131	0·140	0·159	4	12	58	550	8	980	1,420	7,350
,, .	6	$11\frac{1}{2}$	20	0·175	0·184	0·209	3	12	43	750	8	1,330	1,420	7,350
,, .	6	$11\frac{1}{2}$	30	0·258	0·268	0·300	2	12	32·5	600	8	1,065	1,420	7,350
Large . . .	6	$11\frac{1}{2}$	5	0·042	0·046	0·052	6	12	278	600	12	2,400	1,040	5,410
,, . . .	6	$11\frac{1}{2}$	$7\frac{1}{2}$	0·059	0·067	0·075	5	12	208	750	12	3,000	1,350	7,000
,, . . .	6	$11\frac{1}{2}$	10	0·080	0·088	0·102	3	12	188	550	12	2,200	1,350	7,000
,, . . .	6	$11\frac{1}{2}$	20	0·175	0·184	0·209	3	12	43	300	12	1,264	1,420	7,350
,, . . .	8	$11\frac{1}{2}$	30	0·258	0·268	0·300	2	$21\frac{1}{4}$	110	450	12	1,012	2,620	13,560
,, . . .	8	$11\frac{1}{2}$	40	0·343	0·353	0·411	1	$21\frac{1}{4}$	117	600	12	1,350	2,620	13,560
,, . . .	8	$11\frac{1}{2}$	50	0·485	0·495	0·579	1	$21\frac{1}{4}$	51·5	450	12	1,012	2,620	13,560
Hydraulic . .	8	$16\frac{1}{2}$	30	0·258	0·268	0·300	3	$33\frac{1}{2}$	46	135	$22\frac{1}{2}$	840	2,900	15,030
,, . .	8	$16\frac{1}{2}$	40	0·343	0·353	0·411	2	$33\frac{1}{2}$	46	135	$22\frac{1}{2}$	840	3,060	15,860
,, . .	8	$16\frac{1}{2}$	50	0·485	0·495	0·579	2	$33\frac{1}{2}$	46	135	$22\frac{1}{2}$	840	4,180	21,690

The safety buffers of the small press are now made 6 inches in diameter, but the observations were made on presses with 4-inch buffers, as originally used. The pressure on the 6-inch buffer when making size 0·0375 inch would be about 510 lbs.

of filling by hand, the charge being frequently rammed down while being put in with a wooden rammer. Subsequently, for the rifle-press cylinders, a lever rammer of wood was devised, by means of which a similar result was obtained. Finally this was superseded by a small hydraulic rammer, which is still in use. It consists of a small vertical press, having an overhead inverted cylinder with a plunger, the head of which is somewhat smaller than the bore of the pressing cylinder, working downwards from it. The main frame has a holder similar to that in the screw press itself, into which the pressing cylinder can be slipped, and carries a funnel to assist filling in the dough. The cylinder is first filled, the plunger is brought down, compressing the dough into it with moderate force, and is then withdrawn. The vacant space in the cylinder is again filled, and the plunger operated as before. A third repetition of the process leaves the cylinder almost full, and it is then removed to the press. Like the direct-acting hydraulic presses, these rammers have occasionally given rise to slight explosions, probably for the reasons already suggested, and it therefore becomes important to regulate them so that they cannot be worked too quickly. A similar system was employed for charging the cylinders of the intermediate press and the direct-acting hydraulic press; but it was eventually abandoned in the case of the former for the method described, which is now used in all the large screw presses.

In one set of hydraulic presses designed by the Author for a factory where low-pressure water was available, the method adopted was to fill the pressing-cylinder with loose dough after the manner of the large screw presses, and to give it a preliminary compression by turning on the low-pressure water. As soon as this had acted to its full capacity, high-pressure water was let in from an accumulator supplied by a small set of pumps, and the stroke was, by its means, completed. By this method high-pressure water was saved, and a special filling press was dispensed with, though the output per stroke was reduced.

Materials of the Cylinders.—Difficulties were at first experienced through scoring of the cylinders used in the small presses, which were at that time made of mild steel; but finally case-hardened wrought iron was adopted, and is found to answer well. The cylinders of the larger presses are usually made of phosphor bronze; though where lightness is required, as in cases where the cylinders are removed for charging, mild steel is sometimes used, and does not score, the reason probably being that the pressure is much less than that in the small presses. The heads of the

plungers are in all cases made of phosphor bronze. The dies for the smaller sizes are made of hardened steel, and for the larger sizes of phosphor bronze.

The dimensions of the dies are important, and especially exactness in diameter, because it has been found that, in order to keep within the limits of diameter allowed by the Government specification, the size of the die must be carefully watched; and, at any rate, in the larger sizes, it may even require variation to suit circumstances in order to secure a uniform result in the dried product. For instance, when, after the explosion of May, 1894, the mixture of gun-cotton and nitro-glycerine was obtained from other factories, it was found that a different-sized die was required in pressing the larger sizes to produce dry cordite of the correct size; and similarly, any little variation in the system of manufacture or the dryness of the dough may, and often does, require a variation in the die.

Reeling and Cutting-up.

Having been pressed into shape, the cordite, as it may now be called, has to be collected in a manner suitable for the subsequent processes. The first and obvious method was to coil it on reels from which it could be afterwards unwound as required. It was, however, soon evident that this method was only applicable to the smaller sizes; for, as the drying was performed when on the reels, it was found that the larger sizes obtained a permanent set to the curve of the reel, and this made it inconvenient to deal with in the subsequent operations of blending, storing, and making into cartridges. The cordite for the rifle cartridges did not suffer from this cause, and for it the reel system was in every respect the most convenient, and has been invariably adopted.

In the original experiments the cord was wound on reels by hand; but it was clear that this operation ought to be eventually performed by machinery, and therefore the original horizontal machine press had a reeling apparatus attached to it, which supplied the main reason for fitting it with a screw to regulate the pressing, because then the reeling machine could be always made to synchronize with it. The original reels were 9 inches in diameter by 6 inches wide, and it was intended to fill each to a depth of about 1½ inch with cordite, so that suitable flanges were provided. The reeling machine had an automatic contrivance for continually decreasing the speed of the reel, as its diameter was increased by winding on the cordite, and also

a reciprocating guide worked by a cam groove on a rotating cylinder, which distributed the cord evenly over the width of the reel. It was soon found, however, that it was not satisfactory to wind so much on any one reel, as it made the drying process lengthy and uncertain, and did not suit the blending system as finally elaborated. Accordingly the plan of winding only one cylinder charge on each reel was adopted, thus filling a depth equivalent to only six or seven layers of the cord, or less than $\frac{1}{4}$ inch; although this involved the use of a great number of reels, it much facilitated the after operations. The reeling mechanism was also simplified, because, with such a small depth of winding on each reel, the variation in speed was found to be practically negligible, and the elaborate gear for producing this automatically was dispensed with. All that was found necessary was to give the attendant the power of quickly altering the relative speeds of the press and the reel-spindle to a limited extent, to allow for any small variation that might occur, which was accomplished by means of a pair of cone-pulleys and a belt.

In the present form of the rifle cordite press, the reeling gear, Fig. 5, Plate 2, is placed on a separate stand a little way in front of the press, and is driven by a belt from a cone pulley on the worm driving shaft. The pulley is driven by a friction-clutch under the control of the attendant, which is also connected to the belt striking gear, in such a way that at the end of the pressing stroke the reeling machine is automatically stopped, and is not reversed like the press-shaft. When the press is started again, the reeling gear is not started also; but as soon as the cord begins to come out, the attendant takes the end, sticks it on to the reel, and then starts the gear. If he should be a little slow in doing this, so that the cord has collected to any extent, a handle is provided, by means of which the reel can be quickly rotated, independently of the belt driving gear, in order to gather up the slack. Should he find that the reeling is proceeding either too slowly or too fast, a turn or two of another handle in either direction adjusts it at once, or he can at any time stop the reeling for an instant to let a little slack cord accumulate. The distribution on the reel is effected by a guide worked by a cam-groove on a rotating cylinder, as already mentioned in connection with the original machine.

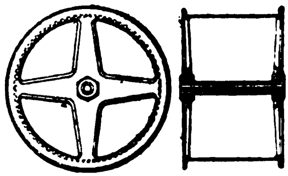
The reels as now used, *Figs. 6*, consist of two stamped sheet-brass ends with shallow flanges, fixed upon an axle consisting of a piece of brass tube, into which a loose driving spindle may be slipped whenever the reel is put into the reeling machine,

or when the cord is to be unwound from it. The drum of the reel has usually been made of thin perforated zinc soldered to the ends, but latterly thin plain brass sheet has been preferred at Waltham for the purpose. With this construction the reels can be closely stacked together in the stores or in the drying-houses, and they are both light and strong. The dimensions are the same as those originally used, namely, 9 inches in diameter by 6 inches wide, but the flanges are only ⅝-inch deep.

As the drying operation lasts for some days, it is evident that each press requires a considerable number of reels, especially if it is worked continuously day and night as at Waltham, which is the most advantageous system to adopt. About 650 are generally provided under these circumstances, so that in a large factory the reels number many thousands and form a not inconsiderable portion of the plant.

Leaving now the cordite as made for the rifles, the next size in practical use is that having a nominal diameter of 0·05 inch. This is required to be cut into lengths of about 11 inches for making into cartridges; and in the early days of the manufacture, it was intended to reel it in a similar manner to the cordite for the rifles, to dry it on the reels, and afterwards to cut it into lengths. This method was for some time adopted, and the Author designed and made a cutting-up machine for the purpose.

Figs. 6.



Scale, 1 inch = 1 foot.

SINGLE-STRAND REEL.

The reeling gear of the rifle press, therefore, was arranged with change-wheels, by which the speed of the reel could be altered to suit this size, leaving the press-speed the same, as the speed of emission would be necessarily slower. It was found, however, that this plan was not altogether satisfactory, and could be improved upon; especially as all the small presses were needed to turn out the quantity of rifle cordite for which there was a demand; and therefore the intermediate presses were called into requisition for the 0·05-inch size.

Multiple dies were used, so that six cords could be pressed simultaneously with a 6-inch cylinder, and as an automatic reeling machine for so many threads would be necessarily complicated, in order to allow for possible variations of speed of emission of the several threads, the authorities at Waltham decided to adopt a primitive though effective system, and do the reeling by hand. Accordingly, a number of wooden stands were

placed round the press, each having a special reel provided with a handle, and a boy to turn it. Each boy took the end of a cord as it came out, and having fixed it on the reel, wound it up with one hand and distributed it evenly across the width with the other. The reels had a diameter of 7·1 inches, and were 14 inches long with no flanges. The share of the charge which fell to the portion of each reel was only enough to make a few layers of cord on it; and at the end of each pressing, they were taken from their stands, and put into a small frame provided with two long horizontal knives so arranged that they worked simultaneously lengthwise of the reel at the ends of a diameter, and consequently cut the charge into halves; the resulting product being therefore a number of lengths of cordite, averaging when dry about 11 inches. The lower halves fell when cut on to a sheet of paper under the frame, and spread themselves out flat; while the upper halves remained on the reel until dexterously removed by the boys. All were then spread out in shallow wooden trays with perforated bottoms, in which they were conveyed to the drying house. Considerable latitude was allowed in the lengths of the pieces, so that the variation which was unavoidable by this process was of no consequence as the limits were not exceeded.

For the larger sizes, from say 0·15 inch diameter and upwards, the requirement was that they should be cut into definite lengths, suitable for bundling together to form the charge for the cartridges. Reeling was, as already stated, found to be inadmissible; and at last the Author contrived a machine which answered the purpose very well, and has been used ever since for all the large presses. It is shown by Fig. 8, Plate 2, and consists of two narrow flat-faced pulleys, with suitable axles and bearings fixed in a framework of wood or iron, some 6 feet apart; and round the pulleys is an endless leather belt 2 inches wide, on which are riveted transversely at appropriate distances apart, a series of short steel knives projecting about $\frac{5}{8}$ inch from the belt. The length of the belt is an exact multiple of the pitch of the knives. Between the pulleys on the top side, the belt passes horizontally along a groove in the framework; and, at about the middle of its length, a gunmetal roller is placed over and across it, carried in a small iron frame. The bottom of the roller is set so as to just touch the tops of the knives as the belt passes under it, and in order to prevent any damage to their edges, the bearings of the roller are held down by light springs, which can yield if required. On the side of the roller remote from the press the sides of the groove are cut away, leaving the belt exposed. The pulley

at this end is driven from the press gear by suitable mechanism, in which is included a pair of cone pulleys and a belt, by which the speed of the knife-belt can be altered as required within certain limits. A friction clutch is also inserted and placed under the control of the attendant; so that the cutting-machine can be started or stopped at any time when the press is at work; and it is also connected to the automatic belt striking gear of the press, so that when the latter reverses for the quick return, the cutting machine stops. As soon as the press is started and the cord begins to come out, the end is taken and laid on the knife belt; the attendant then starts it, and the belt moves along towards the roller, carrying the cord on it, lying over the edges of the knives. As each knife comes to the roller, the cord is forced down on to it, thereby cutting it through; and as it passes beyond the roller to where the sides of the groove are cut away, the lengths thus cut up are picked off the belt by a boy, and are laid in wooden trays with perforated bottoms, for drying. The speed of the belt, and consequently that of the press, is limited by the rate at which the boys can remove the pieces from it, and this has been found to be about 60 feet per minute. Attempts were made to make the removal of the pieces automatic, and an experimental apparatus was constructed for the purpose with moderate success; but it was found that very little labour was likely to be saved thereby. Formerly the nominal standard length of all the large sizes of cordite was 14 inches, with good limits of error; and allowing for shrinkage, the knives were placed on the belts at a pitch of $14\frac{3}{8}$ inches. Only one belt was therefore needed for each press, but latterly several additional lengths have been adopted, and therefore, in order to fully equip a machine, a corresponding number of belts are required, as this is found more practicable than making the knives so that they can be shifted on a single belt. The pulley nearest the press is made movable, so that the varying lengths of belt necessary can be accommodated. For use with direct-acting hydraulic presses where there may not be any shafting to drive the belt-gear, it may be operated quite conveniently by hand; in which case all the speed-regulating mechanism can be dispensed with. The apparatus can be used with either single or multiple dies, as two or three cords can be cut upon it simultaneously as well as one. Of late the leather belts have been superseded by thin steel, as the leather gave some trouble from stretching on various occasions, and seriously affected the pitch of the knives in spite of all the precautions taken to stretch it thoroughly before the knives were fixed.

Drying.

No machinery is involved in this process; the reels from the rifle presses, and the trays from the others, are transported in suitable trucks to the drying-houses, where they are deposited on racks for the necessary space of time. The temperature is maintained by steam-pipes at about 100° F., and the period of time required for the drying varies according to the size of the cordite. The present Waltham practice in this respect is as follows:—

Size	3	requires	3⅓	days.	Size	15	requires	6	days.
,,	3¾	,,	3⅓	,,	,,	20	,,	6	,,
,,	5	,,	5	,,	,,	30	,,	6	,,
,,	7½	,,	6	,,	,,	40	,,	9⅔	,,
,,	10	,,	6	,,	,,	50	,,	15	,,

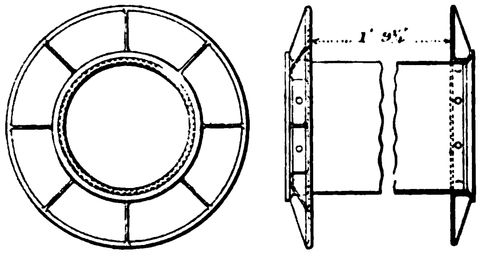
In the early experimental stage, a continuous drying process was proposed, so that the cords after leaving the press might be dried before reeling, but this was soon discovered to be impracticable. Trouble was at one time found with the strands of cord sticking together on the reels, and in order to overcome this a partial or surface-drying between the press and the reel was suggested; but as soon as the final composition and consistency of the material was established, it was found that the sticking was no longer experienced, and no such drying was necessary or desirable.

Blending.

After drying, the cordite manufacture is completed; but, in order to secure the greatest uniformity in the result, the important process of blending has to be carried out, in which a systematic mixing of different batches is made, so that an average quality may be produced. For filling into cartridges, sixty of the cords, 0·0375 inch diameter, are gathered into an untwisted rope, and in this condition are fed into the cartridge-filling machine, which will be described later. Ten of the reels, as they come from the drying-house, have spindles placed in them, and are mounted in a vertical frame with the spindles resting in suitable bearings. Each spindle carries a small pulley, round which a turn of string is taken, one end being fixed to the frame, while the other end terminates with a small weight. The effect is to produce in each reel a slight resistance to turning, thus affording a gentle brake, in order to keep a slight tension on the strings as they are wound off. Opposite this frame, and at a few feet from it, is placed a little

machine, driven by a gut band from the shafting of the factory, which contains a reel similar to those already described, and of the same dimensions, but with a much deeper flange. A vertical arm, with a guide fork on the top, is caused to reciprocate in front of the reel by means of a cam of special shape, and distributes the threads, which are led in one bunch through the fork, evenly over its width. The machine is started and stopped easily and quickly by means of a friction driving attachment. A thread from each of the ten reels is now taken, the ends are passed through the guiding fork and on to the reel of the machine, where they are secured. The machine having been started, the ten threads are gradually wound off the ten reels on to the single one, which is known therefore as the ten-strand reel. Should a thread break, the machine is instantly stopped, the two ends are quickly joined by moistening them with acetone kept handy for the purpose, and the machine is again started. Six of the ten-strand reels thus filled are placed in a frame similar to that already described, in front of which is a machine of similar type to that used for the ten strands, but larger and having on it a reel 8 inches diameter and 22 inches long, with heavy brass ends and deep flanges, the drum being of tin, *Figs. 7.* On this, in a similar way, the contents of the six ten-strand reels are wound, thus forming the required sixty-strand rope.

Figs. 7.



Scale, 1 inch = 1 foot.

SIXTY-STRAND TRANSPORT REEL.

It will now be understood, that, if, in the selection of the single-strand reels to begin with, and then the ten-strand reels from which the completed rope is made, care is exercised to draw them from different batches in a properly organised manner, a very perfect average specimen must necessarily result, and a very certain and uniform blend be obtained. Hence this process of preparing the charge for the rifle cartridges is peculiarly favourable to the production of great uniformity in the ballistics, and consequently in the shooting, a statement which has been amply verified by results. The sixty-strand reels thus filled with cordite are now ready for storing in the magazines until wanted for filling into cartridges.

This machinery was designed at Waltham by Mr. Jenkin, and was made at Woolwich Arsenal.

The blending of the larger sizes is performed by hand in another house, and consists merely in a systematic making up of the cut-up pieces in boxes, designed to contain 100 lbs., by a process of selection from different batches, an operation which is performed twice, so that a very complete mixture is effected. As the boxes are filled with completely blended cordite, they are fastened up, labelled and sent to the magazines until required for making up into cartridges.

The ten-strand re-reeling machines will each deal with 25 lbs. of cordite per hour, the speed of reeling being about 254 feet per minute; and the sixty-strand machine will reel 36½ lbs. per hour, the speed being about 52 feet per minute.

CARTRIDGE-FILLING.

In this section, as in the last, the principal interest lies in filling the rifle cartridges, which is performed by a special machine, whereas the larger cartridges are all made up by hand. The charge for the 0·303-inch, or magazine rifle, is, as already stated, made up of sixty strands of 0·0375-inch diameter cordite, wound on a reel in an untwisted rope. The function of the filling-machine is to feed a certain length of this rope into an empty cartridge-case, and then to cut it off. The necessary attributes of a machine for this purpose are that it should be accurate in its work and not liable to errors, quick in its action, and simple. Experiments were made by the Author and Sir William Anderson at an early stage of the cordite development, to determine the best method of performing the operation. The first proposal was to advance the rope by means of a pair of grooved rollers placed opposite to one another, thus having a circular orifice between them fitting the rope tightly. They were to be rotated by means of an adjustable feed motion to the extent required for one charge; and as each charge was fed into a cartridge, it was to be cut off by a suitable knife outside it. The charge fitted the cartridge case loosely, so that on turning it up the cordite would fall down inside to its proper position. A model was made, but under trial it became at once evident that different portions of the groove in the rollers, owing to their varying radii, would move different amounts for a given degree of rotation of the roller, and the effect would be to move the component threads of the rope irregularly. The Author then devised the follow-

ing plan, which was quite successful, and is the arrangement used up to the present time. Two clamps, which may be called A and B, are disposed upon a base-plate; A is fixed, while B is capable of making a reciprocating movement by sliding in a groove formed in the base-plate, in the sense that it may be made to advance towards or recede from A. Looking at the machine from the side at which the operator sits, B is placed to the right of A. To the left of A there is a fixed trumpet-shaped guide, and to the right of B there is also a fixed guide, after which comes a cutting-knife operated by a hand-lever, and finally a cartridge-case holder. The machine is worked by a pedal, and its operation is as follows:—The top halves of both clamps are turned back, and the rope of cordite coming from the 60-strand reel (which is fixed in a convenient position outside the house containing the filling machine, and communicates with it by a small trap-door so as to minimize chance of accident) is brought in at the left-hand end through the trumpet-guide, then laid in the bottom blocks of the two clamps, and finally passed through the right-hand guide. The top halves of the clamps are then turned down again, the ragged ends of the rope are trimmed off by a cut of the knife, and the machine is ready to work. An empty cartridge-case having been placed in the holder, the operator presses down the pedal; the first result being that clamp B, which is normally held open, closes and grips the rope. At this moment both clamps are closed because A is always normally closed. A further movement of the pedal next opens the clamp A, and then moves B (gripping the rope all the time) to the right, so drawing the rope through A, and pushing it through the right-hand guide into the cartridge-case beyond. As soon as the correct stroke has been made, which is determined by adjustable stops, the movement of the pedal ceases; the knife-lever is pulled over, and the charge is cut off just outside the cartridge-case. The latter is then removed and put into a rack board with its closed end downwards, upon which the charge of cordite, which, as already mentioned, fits it loosely, drops to the bottom. The pedal is now allowed to rise, under the influence of a weighted lever, and the first action of the mechanism is to close the clamp A; at this moment, therefore, again both clamps are gripping the rope. The clamp B is now opened, and finally moves back to the left up to the adjustable stop, slipping over the rope which is held fast by A. By this time the pedal has returned to the top of its stroke, and the machine is again in the normal position ready for another operation.

The clamps act in the opposite sense to one another, that is, when one is open the other is closed; but there is always a brief space of time during the process of reversal when both are closed, so that the rope is always held by one or the other or by both, and can therefore never slip or get out of place. The whole operation, except the cutting off, is performed by pressing the pedal down and allowing it to return, so that as far as the operator is concerned, the action is simple. The machine is illustrated by Figs. 9, Plate 2. The clamps consist each of a laminated top lever, hinged at one side of a laminated bottom block; the leaves in one corresponding with and entering into the spaces in the other. V-shaped notches with rounded bottoms are cut through both, transversely to the laminations; so that when the clamp is closed, there is in effect a round hole formed right through it, of a size to tightly grip the rope of cordite. As the top lever is raised this hole is enlarged, and so frees the rope; but the laminations are sufficiently deep that in working they always interlock with one another, and therefore always form an enclosed opening; and thus the strands of the rope can never get out of place, unless the lever is turned well back. The pressure for giving the grip is derived solely from the weight of the top lever, assisted by a small lead weight at the overhanging end remote from the hinge. The lever of the fixed clamp A overhangs the base-plate on the side remote from the operator, while that of the movable clamp B, overhangs on the side next him. The clamp B is attached to a plate which can slide about in a longitudinal guide-groove in the base-plate. Underneath the base-plate is a rocking-frame, of which the centre fulcrum spindle lies directly under and parallel to the axial line through the clamp openings; and it is carried by bearings attached to the base-plate. From this frame a peg, guided to move in an approximately vertical line, rises through an opening in the plate under the lever of the clamp A; while, from the opposite side, two such pegs rise, one from each end of the frame, joined at the top by a smooth flat strip, which lies under the lever of the clamp B. When this frame is horizontal, neither the single peg nor the strip are in contact with the levers, but are a little clear of them; so that in this position both clamps are free to grip the rope. The frame is connected with a vertical rod coupled to the pedal lever, and exactly follows the pedal movement; so that as it is depressed the strip lowers and the peg rises, allowing the clamp B first to close, then maintaining both closed for an instant, afterwards raising the lever of the clamp A, opening it sufficiently to allow the rope to slip through. The object of the long strip

under the lever of the clamp B is that it can act upon it in any position in which it may be situated.

It remains to describe how the reciprocating movement of B is effected. Under the base-plate a bracket projects downwards, having a fulcrum pin at the end carrying a bell-crank lever, the longer vertical arm of which is connected by a link with the sliding plate of the clamp B. The shorter horizontal arm has a pin in it, carrying an oblong brass slide-block, which works in a slot formed in the vertical rod coming up from the pedal to the rocking frame, and is capable of a definite amount of movement in it; that is to say, the slot is about 1 inch longer than the block. The sliding-plate of the clamp B has a spring-brake attachment on the under side, by which means a small amount of artificial resistance to motion is given to it, and which prevents any unnecessary movement from taking place. The action may now be clearly seen; when the pedal is first pressed down, the block is at the bottom of the slot in the rod, and therefore no motion of the clamp-slide at first takes place; but after the clamps have been reversed, the top of the slot comes into contact with the block, and now the bell-crank lever begins to move, and the slide is drawn forward till the right-hand stop is reached. On allowing the pedal to rise, the clamps are again reversed before any motion of the slide takes place, owing to the clearance between the block and the slot, but as soon as the bottom of the slot reaches to the block, the backward movement commences. While the slide is being moved forwards and backwards, the lever frame controlling the clamps is still moving also, but provision is made so that the unnecessary extra opening of the clamp which thus occurs is of no consequence. In order to prevent the closed clamp from being accidentally pressed down too far, by a hand being laid upon it, or other cause, and so damaging or perhaps even shearing the rope, adjustable stops are provided on the levers, which allow them to be closed only sufficiently tightly to grip and no more.

In the first machine a difficulty arose which is worthy of mention. The rope is pushed by the clamp B through the guide to the right of it, and as this guide has to be smaller than the opening of the cartridge-case, in order to insure that none of the strands catch on the edge of the latter while being fed in and so perhaps damage the charge, it offers a slight resistance to the passage of the rope. The result is, that the individual cords, which are of small diameter and therefore incapable of offering much resistance to thrust, were apt to buckle up at the com-

mencement of the stroke and get caught between the clamp and the guide, so completely spoiling the charge. The only remedy that could be adopted in the first machine was to make the charge in two strokes, thus leaving only half the former length of rope unsupported at the beginning of each stroke; and this was found to answer well and to completely prevent any buckling of the cords. But, for two important reasons, it was desirable to find another solution of the difficulty in subsequent machines: first, because making two strokes to each charge increased the liability to errors, and would not be unlikely to lead to half charges being occasionally put in; and secondly, because it occupied more time, a consideration which would tell seriously when the process came to be worked on a large scale. Many suggestions and some experiments were made, but no satisfactory solution was arrived at until the Author proposed a very simple device which answered perfectly; namely, a movable intermediate support for the rope, placed between the clamp B and the guide, so arranged that it floated between the two, but never left on either side of it a greater unsupported span of rope than half the length of the charge. It consisted of a brass ring loosely encircling the rope carried by a small square pillar, which passed through a slot in the sliding-plate of the clamp B, and was connected with a flat foot lying in an oblong groove on the under side of the plate. Attached to the base-plate, underneath the clamp-slide, was a small stop projecting up into the groove of the sliding-plate already mentioned. When the clamp was in its extreme position at the left-hand side, the distance between the stop and the termination of the groove was a little more than the length of the ring foot, and therefore the foot was constrained to occupy this position at this time, which corresponded with the ring taking up a mid-position between the clamp and the guide. As the clamp moved to the right, the distance between the fixed stop and the end of the groove was increased, and the ring foot could then take up any position between the two; that is, it might either stay where it was, or move forward with the slide altogether or in part, according to how far it was held or not by its own friction. If it remained where it was, the clamp would soon come up to the ring and carry it on with it. If it moved it would go up as far as the guide, and there it would necessarily have to stop. At the end of the stroke the ring, clamp, and guide would all be closed together. This, then, always prevented the unsupported parts of the rope between the clamp B and the right-hand guide from ever exceeding a maximum length, equivalent to a little

over half of the full stroke, and thus obviated all trouble from buckling. All subsequent machines have been fitted with this arrangement.

It will be observed that there is a chance of error in filling with this machine, as it is possible to make a short stroke by not bringing the clamp B quite up to the guide; and therefore, in some of the earlier machines, an attachment was provided which automatically locked the knife-lever until the full stroke had been made, and so prevented the charge from being cut off. As, however, this was found to interfere somewhat with the speed at which the machine could be worked, and as at Woolwich, by a carefully organized system of inspection, a false charge would be almost certain of discovery, and consequently the boys would be obliged to be very careful in their work, this attachment was removed, and was not fitted in the later machines. The knife consists of a circular piece of sheet-steel sharpened all round the circumference, and so arranged that a drawing cut is given when the hand-lever is pulled over, which severs the cords more cleanly than a direct cut. The circular knife admits of being turned round, so that as one part becomes dull a fresh piece of the circumference can be used. Various ideas were entertained of making the machine more automatic and even of working it by power; but the Woolwich authorities seemed to think that this would not be necessary or perhaps desirable, and so no further steps were taken in this direction.

The speed at which the machine can be worked is considerable. After a little practice a boy can fill 6,600 cartridges per day of 8 hours. The weight of cordite in each charge is about 30·2 grains, and the length about 1½ inch. The apparatus as described is fitted on a wooden table 2 feet 6 inches square, and occupies the left-hand corner next the operator, the remainder of the space being utilized for the accommodation of the trays for empty and loaded cases. The empty cases, which have been already capped, are placed bottom upwards in the trays, and as they are filled they are reversed.

As already mentioned, the reels containing the cordite are placed in compartments outside the filling-house, and communicate with it by means of small trap-doors through which the rope of cordite passes. In some instances the reel is enclosed in a sheet-iron casing in the house itself, made like a chimney and passing up through the roof, covered with a light flap to exclude rain but capable of permitting the escape of the gases should the reel by any chance catch fire. A small trap-door in the side communicates

with the filling-machine, and a large door is also provided giving access to the reel. The first arrangement is, however, the better of the two, as the reels need never be brought inside the filling-house.

In case the cordite should from any cause catch fire at the filling machine, in order to prevent it from extending through the trap-door to the reel, a safety device is provided consisting of a heavy brass guillotine door capable of closing the small trap-door, but which is usually held open by a cord passing over pulleys and attached by means of a piece of gun-cotton to a small wooden bridge near the filling machine, under which the cordite rope is made to pass. Should the cordite fire, on reaching the bridge the gun-cotton instantly burns through, releases the door, which at once falls, cutting through the cordite rope, and closing up the opening, and so prevents the fire from spreading to the reel. Although these precautions are rightly taken, it is but fair to say that they seem almost superfluous, as the Author believes that no case of such an accident as they are designed to cope with has ever yet arisen.

After filling, an inspector looks over the trays of cartridges and selects some at haphazard from each to test, which he does by removing the charge and weighing it in a delicate balance, afterwards replacing in the case. The errors thus discovered are few and far between, and it is surprising how accurate the weight of the charge usually is.

Cardboard wads are next inserted by machine, which though perhaps hardly forming part of the present subject, is well worth a brief description. It consists of a frame having at the top a horizontal plate capable of being moved vertically through a certain range by appropriate mechanism, and fitted on its under side with a number of short projecting pieces of brass tube, corresponding in pitch with the cartridge cases as they are placed in the holes of the trays used with the filling machines. The tubes communicate with the hollow interior of the plate, which in its turn is connected by a flexible pipe and cock with a small vacuum pump. Under this plate is another, which can be drawn horizontally in and out of the frame, and having on its upper side a number of shallow circular recesses of suitable dimensions to contain each one wad, their positions when the plate is pushed in corresponding with those of the tubes in the upper plate. Below there is a space into which the tray full of filled cartridges can be slipped. The action is as follows:—A tray of cases having been inserted, the recessed plate is drawn out and a handful of wads is thrown on to it, which by

rubbing them about with the hand soon fill all the recesses. The superfluous wads are then swept off, and the plate is pushed into the frame. The upper plate is now brought down until the tubes touch the wads, whereupon the cock of the vacuum-pump is opened, and immediately the wads stick themselves on to the ends of the tubes. The plate being raised again a little the sliding plate is withdrawn, leaving the wads attached to the ends of the tubes. Finally the tube-plate is lowered, whereby the wads are pushed into the cases waiting below to receive them; and upon breaking the vacuum, they detach themselves from the tubes and remain in the cases, while the tube-plate is raised again to its position. This machine will wad 75,000 cartridges in 8 hours. The cartridges are then necked and bulleted.

The charge of cordite for all the larger sizes of guns is made up by hand entirely. The quantities required are weighed out, and the cords are then bundled together into the form of a cylinder, or in some cases a truncated cone, tied with string and fitted with the appropriate primer, consisting generally of a small bag of gunpowder, sometimes supplemented with a short tube of cordite. If for guns having brass cartridge-cases, such as those known as "quick-firing," the bundle enters the case as it is; but if for others it is enclosed in a suitable bag. The charge for the large guns is made up in several lengths.

Preparation of the Charge for Blank Cartridges.—As mentioned at the commencement of the Paper, a different form of the finished product is required for this purpose, namely thin wafers. Those for the blank cartridges are made in a machine designed by the Government engineers, consisting of a vertical frame perforated with a number of holes, through which are fed by a system of grooved rollers a number of strings of cordite, each being nominally 0·2 inch diameter. In front of this frame a disk is rotated at a speed of about 800 revolutions per minute, carrying four cutting knives, which thus slice up the cords as they come through into thin transverse wafers. The cuttings then drop through the base-plate on which the machine is fixed into a receptacle below, for which purpose two shoots are arranged, one on each side of a vertical centre diaphragm plate, and into either of which the stream of wafers can be directed. When a receptacle under one shoot is full, a slide is moved, and the other shoot comes into operation and diverts the cuttings into a second receptacle, after which the first one is removed and emptied. The thickness of the wafers is 0·0055 inch and the quantity turned out per hour is 12 lbs. A measured quantity of the cuttings is filled into the

cartridge-cases by a simple apparatus calling for no special description. Accuracy is of course of no great importance for blank charges.

General Arrangement of the Machinery in a Cordite Factory.

A convenient arrangement of the machinery in a moderate-sized factory is given in Fig. 10, Plate 2. It consists simply of a long brick wall not less than 14 inches thick, with a series of partition walls of 9-inch brickwork running out from it, dividing it into a number of cells. Each cell has a wooden lean-to roof and front with a door and windows, as light as possible, attached to, but not built into, the walls, in such a way that the brickwork projects well above and beyond the woodwork. In the event, therefore, of an explosion occurring in any cell, the front and roof could be blown out without doing much damage, and the walls would most likely remain sound and prevent any spread of the explosion. The floor may be made of wood covered with linoleum, and most of the machines may be simply bolted down to it, few requiring any regular foundations. Outside the cell doors there is a clean wooden platform joining them, and raised above the ground. No person is allowed on this unless provided with suitable clean leather shoes, in order to avoid bringing any grit into the place, or walking about there in nailed boots. A place (not shown on the drawing) must therefore be provided where the shoes can be put on, and where the workmen can change their clothes. The reason for this precaution is obvious; for although the manufacture is very safe, it is possible to explode the material by impact; and it is therefore important, not only to keep the whole place scrupulously clean and free from pieces of explosive lying about, but also to prevent any chance of such pieces being trodden on by boots with nails in them, which might possibly cause an explosion. It is true experiments have shown that when such an explosion does take place, it is invariably a local one, and does not spread beyond the point immediately affected; but even so, it might be sufficiently unpleasant. One reason why the cordite manufacture is so safe is, that there is no dust, which forms such a terrible source of danger in black powder making. The end compartment on the right, Fig. 10, is the engine-room, containing a suitable engine for driving a line of shafting running overhead through all the cells. It also drives a small set of three-throw pumps supplying an accumulator, which provides the necessary high-pressure water for the larger press, as

well as the charging rammers. The wall-boxes in the partition walls through which the shafting passes are provided with diaphragm plates of iron closely fitting the shafting, so as not to leave open communication between the cells which might assist the spread of fire. The compartment next the engine-room acts as a service store for paste, mineral jelly and acetone. Then come three cells, each with an incorporating machine; two being of the 150-lb. size, and the third a small one capable of being used for re-incorporating the waste material or "heels," that is, the dough that remains in the bottom of the cylinders after each charge. Next, there is a cell containing either a direct-acting hydraulic press, or else an intermediate screw-press, in either case provided with a belt cutting-machine and a set of apparatus for hand reeling and cutting such sizes as 0·05 inch. After this two compartments, each large enough to accommodate two rifle-presses and their accessories; and, if charging rammers are used, one is placed in each compartment to serve the two presses contained therein. Finally there is a cell containing one ten-strand and one sixty-strand re-reeling machine with their stands, which will probably prove sufficient in practice to deal with all the rifle cordite produced; though, as will be seen by figures already given, if all four presses are continuously worked on rifle cordite to their full capacity, the ten-strand machine will hardly be able to keep pace with them, and a second one would be required. There is plenty of margin in the sixty-strand machine, its output being nearly 50 per cent. greater than that of ten-strand. If an extension of the factory is required, a similar set of cells may be built on the other side of the main wall, with a second line of shafting through them.

Besides the machinery-house, several other buildings are required for drying, blending, &c., but these do not properly enter into the scope of the Paper. The boilers are placed separately at a proper distance from the danger buildings, and steam for driving the engine and for warming is conveyed to the several houses by long pipes. The machinery-house may be warmed by the exhaust from the engine.

Electric lighting is the most convenient to adopt, and must in England be installed in accordance with the Home Office regulations. The electric lighting arrangements of the Waltham factory have been described[1] by Mr. C. F. Jenkin; but it should be remembered that they do not necessarily comply with the Home Office rules,

[1] Minutes of Proceedings Inst. C.E., vol. cx. p. 367.

from the operation of which the Government factories are excluded. For the same reason the arrangements of the machinery- and other buildings at Waltham are not necessarily such as private manufacturers would be at liberty to adopt. The building which has been described would, it is believed, generally receive the approval of the Home Office, though in some cases local circumstances may necessitate modifications.

The Author is indebted to Colonel Ormsby, the Superintendent of the Waltham Abbey Factory, for much of the information contained in the Paper.

The Paper is accompanied by eleven drawings, from which Plate 2 and the *Figs.* in the text have been prepared.

Discussion.

Sir JOHN WOLFE BARRY, K.C.B., President, thought the members would all agree that they had listened to an admirable description of interesting and ingenious mechanism, each machine following its fellow through a very complicated process, and producing at last a perfect whole. These trains of machines reminded him of the celebrated block machinery at Portsmouth, designed by Sir Isambard Brunel, where each machine in regular sequence at last produced a perfect block, and was the admiration of all as much now as when it was first put to work. Equally the Author's train of machines, which at last produced a cartridge under conditions of further difficulty from the risk of explosions, was a most creditable performance, and was one which all present, as engineers, might well be proud of. The Author was to be congratulated on the results which had been attained, and he felt sure that the members would unanimously accord to him a hearty vote of thanks for having brought the subject before them. Sir John Wolfe Barry.

Mr. E. W. ANDERSON said that, through the kindness of Messrs. Werner Pfleiderer and Perkins, he was able to exhibit a small incorporating machine, which he would set in motion at the close of the meeting, so that the action of the blades might be observed. He also exhibited and worked one of the rifle cartridge-filling machines kindly sent by Colonel Bainbridge, C.B., Superintendent of the Royal Laboratory. He would burn a short length of cordite, and it would be seen that it did not produce any very alarming effects. It burnt quite harmlessly in the air. Mr. Anderson.

Sir JOHN WOLFE BARRY asked if that were a single thread? Sir John Wolfe Barry.

Mr. ANDERSON said that it was. He then drew attention to specimens he exhibited to show the different sizes made at Waltham Abbey. He also showed a cylinder of the rifle press, a single-strand reel, a hand reel, and a belt for the cutting-up machine shown in Fig. 8, Plate 2. The belt was made of steel, which was, as stated in the Paper, found to be preferable to leather. As to the accuracy of the results obtained from the filling machine, he had been informed that the charges usually varied from the normal by maximum plus or minus limits of only $\frac{1}{10}$ grain. The limits allowed by the Government were $\frac{1}{5}$ grain on each side of the normal, but greater accuracy was generally obtained. Mr. Anderson.

Lieut.-General Sir Henry Brackenbury.

Lieutenant-General Sir HENRY BRACKENBURY, K.C.B., while regretting his inability to make any useful remarks on the machinery described in the Paper, thought it might interest the meeting to hear from him, as President of the Ordnance Committee, something about the finished products of that machinery. Several years' experience had now been obtained with cordite, and he thought he might safely say that it gave great satisfaction. It had three very important qualities as a propellent: in the first place, it had the great quality of safety; in the second place, it was stable under various climatic conditions; and thirdly, it had the advantage of uniformity with regard to its ballistics. With reference to its safety, the Author had stated that it was a safe material in manufacture, and he would add that for storage in magazines it was certainly a safer material than gunpowder. A series of experiments had recently been carried out by the Ordnance Committee for a Committee on Danger Buildings, which had been appointed by the War Office, as to the effect of igniting cordite in cases of weak and strong construction, both in single cases and in cases stacked together, and an explosion was produced only in one instance, and that, as was pointed out beforehand, was under conditions which could not possibly occur upon service. 100 lbs. of the finest-sized cordite—which was, of course, the most explosive—were ignited electrically, in an ordinary wooden case. Nothing was obtained but a flame—there was no explosion. Then the same quantity was ignited in a metal-lined case, and again a flame was produced, but no explosion. Next 130 lbs. were ignited in a solid metal case, and a flame was produced, the lid of the case being blown up to the roof, but there was no explosion. Then twelve wooden cases were stacked together, piled one on top of another. One of the bottom cases was then ignited electrically. The cordite in that one case burned, the other cases next to it were thrown over, but none of them were ignited. The same experiment was tried in metal-lined cases, with the same result. Then thirteen metal cylinders, each containing 130 lbs. of fine cordite, were stacked, with the lid of the one cylinder against the base of another cylinder, and a very violent explosion, at the Arsenal at Woolwich, occurred. But the conditions were, as had previously been pointed out, such as could never possibly occur on service. Cordite of that fine size was never packed into metal cylinders, which were only used for the large cordite, which was much less explosive. 83¾ lbs. of the largest sized cordite was the maximum charge ever packed into one of these cylinders. Directly this explosion had taken place, the Ordnance Committee asked to be allowed

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to repeat the experiment with cylinders filled as they would be actually filled on service. Thirteen cylinders, each containing $83\frac{3}{4}$ lbs. of large-sized cordite, were stacked together in exactly the same way as in the experiment which resulted in explosion. One of the lowest cylinders was ignited electrically. The cordite in that one cylinder burned, but none of the others were ignited. Subsequently a great number of cases of cordite were stacked in a light magazine specially built for the occasion, and one of the lowest cases was ignited electrically. That one case burned, the light shutters of the magazine were blown out, some cordite which had been placed uncovered close to the doors of the magazine was ignited, but not one single case in the magazine was ignited except the one that was ignited electrically. He thought that showed that cordite was an extraordinarily safe material. As regards its stability, experiments had been carried out in India both in a very dry climate at Lahore, and in a very damp climate at Dumdum, close to Calcutta. The cordite was stored there under conditions of great heat, both dry heat and damp heat, was constantly tested, and after one year and a half was found not to have to any serious extent deteriorated. When he had been in India, at the time of the Chitral Expedition, small-arm cartridges, which had been left out on the rocks in the blazing sun, where they must have been exposed to a temperature of 150° to 180° for days, and even weeks—were recovered and fired, and they gave correct ballistics. Similar results had been obtained with cordite exposed to extreme cold in the Jackson-Harmsworth Arctic Expedition. All this showed that cordite was an excellently stable material. Its uniformity, as manufactured, might distinctly be said to be good, but he did not think that perfection had yet been arrived at. It was a fact—the Author had to some extent accounted for it in explaining that with the direct-acting hydraulic press the diameter of the squeezed cordite was not always uniform—it was a fact that sticks which ought to be exactly the same weight were not exactly the same weight. In the specifications which were determined by the Ordnance Committee, a certain plus or minus amount was allowed over the exact weight which the sticks ought to have. At one time the Committee was told that there was a difficulty in getting uniformity in the size and weight of sticks at Waltham Abbey, and they were a little alarmed lest that should cause a want of uniformity in ballistics. A series of experiments was carried out to ascertain the difference in the ballistics if a charge was composed entirely of sticks of exactly the

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right weight, or if it was composed of a blend of sticks some of which were over that weight and some of which were under it. The maximum and the minimum taken were the extremes within which the Director-General of Ordnance Factories, Sir William Anderson, had said the cordite could always be produced. The curious and interesting result was found that the same ballistics were obtained with a charge composed of 50 per cent. of the maximum and 50 per cent. of the minimum asked for that were obtained when every stick in the charge was of the exact mean weight. So that it appeared that slight deviations in the weight of the sticks did not really influence the ballistics as long as the cordite was well blended. The results now obtained with that product might perhaps be instanced by the fact that one of the last designs of guns which had been approved for the Navy—a 12-inch breech-loading gun—would have a charge of about 230 lbs. of the largest-sized cordite. With that charge, a velocity of 2,700 foot-seconds would be obtained for an 850-lb. projectile, which gave a striking energy to the shot of between 44,000 foot-tons and 45,000 foot-tons. It was often said that cordite wore out the guns too fast. There was no doubt that with the large guns very rapid erosion had occurred. In the inquiry into this matter no one's services had been more valuable than those of two Past-Presidents of the Institution whom the Ordnance Committee was very proud to have among its members, Sir Frederick Bramwell and Sir Benjamin Baker. There was certainly very rapid erosion of the large guns in the present day; but it was not fair to say that that was due to cordite. It was due to the high ballistics required; it was due to the great velocity which was required to be given to the projectile, and consequently to the very large charges that had to be used, whether of gunpowder or of cordite. In favour of cordite, it might be said that the erosion was not of the same very bad character for the life of the gun as the erosion caused by gunpowder. Gunpowder pitted and scored deeply into the gun and guttered it; cordite generally wore away the surface of the lands more than of the grooves, and also, to a certain extent, the surfaces of the grooves, and it rapidly tended to convert the breech end of a rifled gun into something very like a smooth-bore gun. When that took place the shot went further up the bore, the air space for the charge was enlarged, the gravimetric density of the charge became less, and a lower velocity was obtained from the gun; but this could be remedied by inserting a new short liner in the breech end of the gun, and the life of the gun was, in his opinion, not more endangered by cordite than it was by gunpowder.

Mr. C. FREWEN JENKIN had been in charge of the machinery at Waltham Abbey when the manufacture of cordite was started, and wished to refer to the reeling machinery which he had designed at that time. When the cordite was wound on a reel, it could not be wound like cotton on a spool, because the strands sank through one another and became entangled, so that they would not come off. It was consequently wound on like a screw of very rapid pitch, that was to say, as it wound on, the guide arms moved rapidly backwards and forwards along the reel, and guided it on the reel in a network form. Owing to the rapid pitch with which the thread was laid on to the reel, a difficulty occurred at the ends of the reel. If any ordinary guiding mechanism, such as a crank or an endless screw, were used, the thread was piled up towards the end of the reel and left hollow in the middle, somewhat in the shape of a ball of string. The result was that as the reel was shifted about the threads fell together and became loose. He had therefore to design an arrangement which would lay the cordite in an even layer on the reel. That could only be done by means of a cam, which seemed otherwise a clumsy method. There was also considerable difficulty in filling reels with square flanges quite up to the ends, because the rims of the flanges caught the strand first, owing to the obliquity with which it was paid on. A cotton reel had conical flanges which overcame this difficulty, but introduced complexity in the paying on gear because the layers increased in length as the reel filled up. Owing, however, to the shape of the strand of cordite which was wound on like a flat ribbon, the side of the strand which caught first on the flanges was pushed over by the rest and so filled the corners, and by suitably shaping the cam the ends of the reel could be filled and kept of equal diameter with the body. The sixty-strand reel itself carried the Author's design a step further—the Author arranged his small reels without a spindle; he abandoned the spokes also, and the reels were nothing but a shell. These were carried in the machine by cast-iron flanges fixed on the spindle of the reel. The guiding arm on the sixty-strand reeling-machine, which, as the Author explained, terminated in a comb-like guide, had a screw adjustment for setting it sideways, so that any irregularities in the position of the reel could be compensated for, and the reel was filled evenly to both ends. Mr. Jenkin.

Mr. OSCAR GUTTMANN desired to congratulate the Author upon the machinery he had designed to overcome the great difficulties presented by the new explosive. Its properties were unknown Mr. Guttmann.

Mr. Guttmann. at the time, and the difficulties seemed almost insurmountable. On p. 71 of the Paper the Author stated that nitro-glycerine and gun-cotton were incorporated by hand till a proper mixture or solution had taken place. He thought he overlooked the fact that no solution took place; it could not dissolve by simply mixing it by hand. It was also stated that when the two explosive substances were mixed they resulted in a comparatively inert compound which, though highly inflammable, was not easy to explode. He would not like to see manufacturers or others led to think that it was not easy to explode. It was no more difficult to explode than the two materials singly. On p. 74 the Author stated, "In this particular case the dough is invariably circular in section." He thought the Author referred to the cord. It was stated on p. 75 that, in the original screw-press, "the cord was shot out for an instant at great speed, so that the friction of its passage through the die was sufficient to ignite it." The explanation of that ignition might perhaps not lie in the fact that the cordite had been shot out at a great speed. Engineers accustomed to deal with such highly-inflammable substances as acetone or benzene would know that great friction would in some cases cause electricity to be generated; in other cases the pressure would result in igniting the volatile spirit, and not the nitro-glycerine itself. He had known in a benzene-extracting apparatus the gauge-glass to burst. The apparatus was at a pressure of about 30 lbs. per square inch; the gauge-glass was then 2 feet from the wall, and the force of the benzene striking against the wall was sufficient to ignite it and cause a very serious accident. There was one passage in which he took especial interest, although not as a manufacturer. It was stated that the screw-press had so many advantages over the hydraulic press, and that the screw-press was not liable to so many accidents as the hydraulic press. He believed the facts were not stated quite correctly in the Paper. He understood that quite as many accidents, if they could be called accidents, had happened with the screw-press as with the hydraulic press. But, although he knew of two accidents, where the detonation was of a larger character, there was not a single instance in which it had become a true explosion. In the manufacture of smokeless powders in general the powder had either to be rolled or pressed, or such operations performed where there was a great amount of pressure or friction put on the material, and in all those cases there were slight deflagrations, slight cracklings, which might in the beginning alarm the workmen, but really amounted to nothing more than a

local deflagration of the material. Such cases were of common occurrence with smokeless powders of the flake variety, like ballistite or German powder, and they would be of quite common occurrence with cordite if precautions were not taken. In the case of flake powders, the difficulty was greater than in the case of cordite, because it was necessary to incorporate and roll it between two steam-heated rollers, or sometimes between cold rollers, which produced a great amount of friction and were bound to touch portions of undissolved nitro-cellulose or similar material. In the case of cordite, there was a die and a plunger, and if the two were kept, as the Author pointed out on p. 79, in such a position as to be truly concentric, there ought not to be any danger of such crackling. The hydraulic press shown in Fig. 4, Plate 2, presented one great objection, namely, that whilst in a screw-press the piston was guided to a certain extent—the lower part was rather long, and not guided—in the hydraulic press there were three or four long legs on a little table which carried a high mould, and that was supposed to enter the piston perfectly freely. The only guidance was the cup leather on the ram and the guides on the columns. He thought it would depend largely upon the workmanship of those columns and upon the perfect coincidence of the three columns and the table and mould, whether they were perfectly concentric or not. The legs of the table were really held down by bolts and screws only, and the slightest vibration, expansion of metal, owing to the heat in the room, would cause the whole arrangement to swerve, and there would be friction on the sides between the mould and the piston, which might cause sufficient heat to deflagrate parts of the material. In order, therefore, to make a hydraulic press perfect, it would, in his opinion, be necessary, in the first instance, to guide the table which carried the mould on the columns, so as to have a double guide for that press. The die might with advantage be encased and guided so that it could not swerve. At the same time, he believed that if the mould were made so as to have a little play, say 1½ inch or 1 inch, just to move vertically and be independent of the movement of the ram, it would be found that only half the pressure which was used at present would be required. Those who were familiar with pressing gun-cotton for military purposes would know that such precautions and appliances were quite common, and it would only be necessary to take the same precautions as were taken in the manufacture of gun-cotton for that purpose in order to arrive at perfection. He did not see why a screw-press should then have any less liability to accident than a hydraulic press; on the contrary, Mr. Guttmann.

Mr. Guttmann. he thought a hydraulic press would give a very uniform and good powder. It might be desirable, and it might be worth the Author's consideration later, to make the hydraulic press adjustable to a certain extent; that was, it should be in the hands of the workman to increase or diminish the pressure, and therefore increase or diminish the rate of the issue. That could be accomplished very easily. It was stated later in the Paper that a new design of the intermediate press had been made, in which the cylinders were movable by means of a small crane. That was a detail which could be solved in many ways. In most cases it was solved in another way than by means of a crane, so that the change of moulds was more rapid than in the present instance. On p. 84, the Author stated that mild steel was being used for cylinders, and that those cylinders did not score. He had no doubt the Author had considered the matter deeply, and if he had found that mild steel was best for the purpose, he had certainly rendered great service to the various manufacturers. So far, the experience with such presses had shown that nothing but the hardest steel or manganese bronze would suffice. In fact, in Germany Messrs. Krupp had to make a special steel for the gun-cotton or smokeless powder presses. If mild steel would suffice, it was much easier to make, and much preferable. He observed from the plan which the Author had given of the general arrangement of machinery in a cordite factory, Fig. 10, Plate 2, he used 9-inch partition walls, which he did not think the inspectors of explosives would pass, and they certainly would not pass buildings with all the doors opening inwards instead of outwards.

Mr. Ristori. Mr. E. J. Ristori had been familiar with nitro-glycerine explosive manufacture since 1888, and he fully confirmed the statement of the last speaker that in the experience of other factories the mild steel was not suitable for the purpose indicated in the Paper. It was always found that chilled cast-iron or manganese bronze was more suitable than mild steel. With regard to the remarks of General Brackenbury with reference to the safety and quality of nitro-glycerine explosives, there was no doubt that the quality was very good; he did not believe that it was yet realized how good it was. It was absolutely an ideal powder. With the black powder and the cocoa-powder it was seldom known what was going to happen in the gun. The present powder burnt regularly from the surface inwards. It was possible to obtain the pressure in the gun just where it was wanted, which was one of the greatest advantages in ballistics. He had had a great many guns to calculate, and he knew what that meant with regard to safety.

A mixture of nitro-glycerine and nitro-cellulose would hardly give the impression of a safe explosive, but there was no doubt that these nitro-glycerine powders were far safer than the old powders. He had had one experience which he thought proved the safety of the powder. At the terrible fire at Avigliana in 1891 there were about 30 tons of that powder burnt out. This factory was not under the strict rules of the Explosives Act, and many different operations were allowed to be carried on in the same building with a good deal of powder about, and for some cause which had not been discovered, the powder took fire, and the whole 30 tons burnt off. But there was no explosion whatever. He had seen the place a short time afterwards, and there was not a trace of any explosion. The wood of the ceiling was hardly charred; the wood of some of the machinery was just blackened, and that was all, and the whole of the machinery was as good as it was before. The general impression the Paper had given him was that the machinery described was rather slow. He and his friends had had the problem put to them in the beginning of 1889 to make 450 tons of that powder in 6 months, to erect all the machinery, make the powder and load many million cartridges. It was done, but he was sure that this machinery would not have done it. With regard to the incorporators, only 1 ton was dealt with weekly in each machine. That meant that in the case he cited many incorporating machines would have to be used to do the work. With regard to the filling-machines also, they filled 6,600 cartridges in a day. That only gave about 30 lbs. of cordite used per day, so that if many tons of cordite were being made, and many million cartridges were required in a short time, a good many machines would be necessary. He had no doubt that the machine worked well, but he thought it was not designed for quickness, and he thought that machinery might be designed which would do the work considerably more cheaply and quickly. He had also remarked the fact of the doors opening inwards, but he thought they might open both ways. Mr. Ristori.

Mr. R. B. Pollitt remarked that the idea of forming explosives into a cord was much older than the invention of cordite. As far back as 1862, a patent had been granted to Thomas Davey of Tuckingmill for a process relating to improvements in the manufacture of gunpowder, in which the squirting of the plastic material was claimed. Also in the manufacture of blasting gelatine, from the commencement, he believed, a squirting process had been used for producing thick cords. About the time cordite was being invented, Mr. Pollitt.

Mr. Pollitt. the idea of squirting explosives seemed to have been in the minds of several inventors, amongst whom was his predecessor at Stowmarket, the late Mr. Innes Anderson. That gentleman had patented a smokeless powder, an especial feature in the manufacture of which was the squirting process. He experimented largely with various forms from a plain cylindrical tube to those with internal radial partitions. Of the machines described in the Paper, those of the most modern type were, no doubt, developments of the older and first used machines. There was no doubt that the machinery now in use did its work efficiently, but he thought the Author would be the last person to claim that finality had been attained. The need for the utmost simplicity in machinery for the manufacture of explosives would, no doubt, be apparent. He believed it was a well-established fact, that the manufacture of cordite was remarkably free from danger; still, the presence of moving gearing, such as belting and so forth, in the building in which the explosives were being manipulated, was, as a general rule, objectionable, and, for that reason, he would prefer the direct-acting press to a screw-press driven by belting and other gearing. With direct-acting presses the use of gearing in the building could almost, if not entirely, be obviated. In connection with the three-column press, he would like to call attention to the excessive weight of the pressing cylinder. In the first pressing cylinder that he had seen used for that particular form of press, the weight was somewhat less than in those now used, and it would be interesting if the Author could state what had led to the increase of weight which had taken place. The cylinder was now so heavy that the use of tackle for taking it in and out of the table of the press was almost essential, and the operation of lifting heavy weights by means of tackle in a building containing explosives was objectionable. There was another point in connection with the pressing cylinders, namely, that mild-steel cylinders had been found less suitable than those of phosphor-bronze. Mild steel would seem to be the most promising material for getting a handy pressing cylinder combined with sufficient strength, and the scoring which was mentioned as having taken place was difficult to account for, unless the presence of foreign particles of grit in the cordite, or want of alignment or concentricity between the pressing cylinder and the piston was assumed. Still, it would be interesting to know why a continuous screw at the base had been found preferable to an interrupted one. At first sight it would appear that an interrupted screw was not only more handy, but quite as efficacious as the

continuous one, and the improvement of any such small details, which would lead to a more easy working of the process, would be a distinct advantage. With regard to the statement made on page 74, that brush collectors were placed near the driving belt of the mixing-machines in order to prevent the possibility of dangerous electrical discharges, he thought that was a matter which pointed to the necessity of keeping moving belting and all such gearing outside danger buildings. In some quarters great importance had been attached to keeping the cordite paste free from included air-bubbles prior to pressing. From the description given in the Paper, it would appear that a simple filling of the pressing cylinder, by means of a hydraulic rammer, was sufficient, and that more elaborate precautions, such as were provided for in a process patented by the firm of Krupp-Grusonwerk, were not necessary. In the process to which he alluded, the explosive paste was formed by means of rollers into a more or less narrow sheet, which was rolled into a tight coil and dropped into the pressing cylinder. A mandrel was then forced upwards through the centre of the coil, which compressed the component layers of the material in the cylinder and, at the same time, expelled the air. The pressing ram then descended and forced out the explosive paste through suitable nozzles, at the same time driving downwards the mandrel, which had been used for pressing together the layers of the coiled sheet. There seemed to be good reasons for believing that treating an explosive paste under rolls was advantageous, quite apart from any question of getting rid of air-bubbles, inasmuch as it led to a more thorough incorporation of the ingredients. It would be interesting if the Author, or any gentleman present who had had experience of that process, could give particulars, especially as to whether the process had actually been used on a manufacturing scale, and, if so, where, and with what results. The process seemed to possess some points of merit, particularly with regard to obtaining a more uniform product just before squirting. There was another point upon which he should like to ask the Author for information, namely, in connection with the single-strand reels. He should like to know in what respects the sheet-brass reels were superior to those made of perforated zinc. Possibly it was that it had been found that the sheet-brass made a stronger reel on which the drying took place equally as well as on those of zinc. He was supposing, of course, that the perforated zinc was adopted at first with a view of facilitating the drying. With regard to the drying process, it would appear from the description Mr. Pollitt.

Mr. Pollitt. in the Paper, that at Waltham Abbey the cordite was practically stewed in a mixture of acetone vapour and air, whereas, in most other factories, the system of drying used was that of blowing warm air through the building. He would like to know whether there was any objection to that, or, on the other hand, whether it was unnecessary, because the simple heating of the building by steam-pipes, if it were equally efficient, would be gladly used by manufacturers, in order to save the cost of running a fan for driving in the warm air. With regard to the general arrangement of the factory, the one shown in Fig. 10, Plate 2, had been adopted in at least two private factories with which he was acquainted, and was fairly handy, and on the whole a convenient one. There was one somewhat misleading statement about it, namely, that 14-inch back walls and 9-inch partition walls were suitable. He doubted whether Her Majesty's Inspectors of Explosives would sanction the 9-inch partition wall. At any rate, in two cases, with which he was acquainted, they had refused to sanction such walls, and insisted on having 14 inches, at least.

Mr. Rigby. Mr. JOHN RIGBY thought it extraordinary that among all the inventions which had been adopted in foreign countries for military explosives, none, so far as he knew, had followed the English initiative in giving their military explosive the form of cordite. In some cases they had made cordite, and then had cut it up into little chunks, and in that form it was a cylindrite, but not a cordite. Cordite had, for military purposes, some very striking advantages, and it seemed very strange that those had not been acknowledged, at least for small-arm purposes. In the first place the method of measuring, and at the same time weighing the charge into a small-arm cartridge, was very much simplified in cordite over any other form of explosive that he was acquainted with, which had been used for the same purpose. When nitro-glycerine began to be used, the first that was submitted and successfully tried was the Nobel ballistite. That was presented in the form of thin plates about $\frac{1}{100}$ inch thick and $\frac{1}{10}$ inch square. It was an awkward form of grain to measure into a small cartridge case, because those very much flattened plates packed in a very irregular way in a measure. and in fact it was not possible to obtain really uniform results without weighing every charge. The same remark applied, as far as he knew, to all the granular, or more or less granular, forms of smokeless powder which were used for military purposes, He had had experience of almost all the modern powders, such as Troisdorf, the German powder, the Swiss powder, the English

powders, rifleite, cannonite, ballistite in different forms, and so forth; but he knew none which could be loaded in large quantities with the admirable accuracy with which the small-arm cartridges supplied to British troops were loaded. In fact, sixty little lengths of that cordite, which weighed almost exactly ½ grain each, gave a charge of 30 grains and a tenth, or two-tenths, as the case might be. The advantage was that, if a sample of cordite did not weigh exactly ½ grain to a single stick, the machine could be varied in such a way as to always keep to that extreme degree of weight accuracy. It had been advanced that a cord was not a very good form for an explosive in order to keep a constant pressure in the bore. Supposing that the material burnt at an even rate under even pressure, the sphere, or spherical grain, was the worst form of all, because the total surface under deflagration at any instant was very rapidly diminishing, and towards the muzzle of the gun, when the process of combustion had gone on for some time, this surface was very much reduced indeed, and the evolution of gas was consequently small. From that point of view the flat plate appeared to be the best, because the surface burning on each side was almost constant in area until the particle was burnt out altogether, and it was very remarkable, to those who had not handled that material very much, how perfectly uniformly the diminution of thickness went on on the different surfaces. The little plates which were blown out, partly burnt or nearly burnt, were almost exactly similar in form to what they were originally; they did not burn away at the edge quicker than they did on the flat, but they retained the same general shape as they had at first with dimensions uniformly reduced. There was one thing that gave cordite the advantage in a small-arm over granular powders. If the latter were used, of any kind so proportioned that it did not altogether burn in the bore (and that must be the case to a certain extent, as the combustion of the grains could not be exactly synchronized with the time the bullet was in the barrel) a certain amount of the partly-burnt grains must be blown out. With cordite there was a considerable amount of cord to be found in front of the muzzle of the gun burnt away to a very thin thread, although not much reduced in length; but none of these remained in the barrel. The great inconvenience found with the Nobel ballistite, which had otherwise admirable ballistic qualities, was that some of those little plates remained in the bore of the barrel, and in extracting the cartridge a few which were in the cartridge-case fell into the mechanism and into the magazine, and Mr. Rigby.

Mr. Rigby. they were also liable to fall upon that part of the barrel, the bullet chamber, the consequence of which generally was that the next cartridge inserted jammed slightly, owing to the little plates getting between the bullets and the side of the barrel. Cordite was entirely free from that, no matter how slow-burning it might be. Whether large cord was used or a small cord, it was all blown out of the muzzle, and he had never known an instance in which a cord or part of a cord was left in the barrel or in the mechanism to incommode the next shot. In that connection he remembered reading an American patent not very long ago in connection with an improvement in the machine-gun so arranged that a blast of air would be driven through the barrel every time it was opened, in order to blow out the remains of the previous charge, and to prevent the jamming, which was found most inconvenient to their system. The American powders which he had seen, and from which he had obtained the best results, were made in cordite form and cut up into little pieces, and he found that these had the same disadvantage; where they were not wholly consumed, some of those little rather plastic, sticky pieces remained in the bore, or were likely to foul the mechanism. These remarks, he thought, were justified on this occasion because if the nitro-glycerine used for cordite were not made in that form—if the two things were not wedded together—an admirable compound in itself, and the form in which it was manufactured, none of that machinery would be required.

Mr. Rigg. Mr. ARTHUR RIGG observed, in relation to the chemistry of the subject, that nitro-glycerine and gun-cotton were made by precisely the same process; the nitrification was effected in exactly the same manner, and it almost seemed as if in Nature there was a material which could be used direct. Enormous quantities of certain sea-weeds were sent abroad, and he had often thought that the ostensible use was not the real one, and that the real use might be to make explosives, because some of those sea-weeds contained iodine, and various other substances, which were ingredients in remarkably good explosives. A previous speaker had pointed out that the press shown in Fig. 4, Plate 2, was not very well guided, but he thought the Fig. was a diagram and not a working drawing, and that there really were three pillars. The elementary principle in designing machinery was to keep the parts which it was not necessary to observe out of the way, and all the parts which required attention handy. In the machine referred to the hydraulic press was placed below and the pressure-box for cordite was clear.

In the other machines, Figs. 2 and 3, the whole machine seemed very top-heavy and the pressure-box was kept at the bottom, which he thought would be very disadvantageous. The press shown in Fig. 4, Plate 2, would be much more convenient to get at, and there would not be the trouble, as in Fig. 3, of catching the drops of oil. There were two principles of importance in connection with the squirting of cordite: one was to keep a constant pressure in the hydraulic press, and the other was to keep a constant rate of movement. The Author had evidently been very careful to keep the rate of movement rather than the pressure constant, and that was the object of the gearing. He did not admit that the corresponding result might not be obtained with hydraulics, because he thought hydraulics could do a great deal better than gearing. If the rate could be regulated by hydraulic arrangements it would simplify those machines enormously; it would reduce the price by one-half, and make them much more comfortable machines to work with. For other purposes he had seen and used himself the hydraulic means for obtaining a regular speed. It was used in Sir Henry Bessemer's telescope, which could be moved from the horizon to the zenith in a few minutes, or it would take about a week for the same movement. So it showed in that case that there was not the least difficulty in regulating the rate of movement quite independently of the pressure. Very often in designing a machine the changes which had taken place were forgotten, and it was not noticed that the original idea had been greatly modified. He thought that if the press were turned upside down and properly guided, and made with a hydraulic arrangement for setting the speed at which the rams travelled, that it would be very much more convenient and handy for practical use besides being vastly cheaper. Mr. Rigg.

Mr. E. Kraftmeier said that with regard to the kind of building used in the early days at Waltham Abbey, he believed they were almost entirely of corrugated-iron, and he thought that the kind of building shown in Fig. 10, Plate 2, was an adaptation of the ordinary gunpowder buildings at the Chilworth factory, but which were now used for the manufacture of cordite. He remembered that in the first building erected at Waltham Abbey a great many incorporating machines were standing in one building opposite to each other, and it was thought that that was a dangerous arrangement. The Chilworth Company took up the manufacture of cordite, being the first private manufacturers, immediately after the Government, and it was then that they adopted that arrangement as shown on the Author's plan. He Mr. Kraftmeier.

Mr. Kraftmeier. believed that a great many manufacturers found that a good deal of air was being imprisoned when the cords were being pressed. He was aware that cords had been fired at Woolwich which showed many blisters, and others which showed comparatively few, and that both had given practically the same result, so that for all practical purposes that matter seemed to be of very little importance. With reference to ballistics he felt very great hesitation in expressing any opinion, especially in the presence of the man (Sir Andrew Noble) who had perhaps done most in England in the matter of explosives for ballistic purposes. With regard to Mr. Rigby's remarks, he was aware that a great many Continental powers were using the granular kind of small-arm powder, and that their requirements, with reference to regularity of results, velocity, pressure and getting the same quantity of powder into each cartridge-case, were very much more stringent than those enforced in England, and that notwithstanding all those difficulties had been overcome with granular powder, and he believed most other Powers preferred the granular powder, with small arms, more especially based entirely on the nitro-cellulose base, as nitro-glycerine had given a great deal of erosion in small arms, and besides had the further disadvantage that when fired at night it gave a considerable amount of flame at the muzzle. Some European Governments had laid it down as an absolute requirement that when small-arm cartridges were being used no fire should show at the muzzle. For the larger guns a great deal of attention was already being paid to the question of erosion. It was very difficult to eliminate that, but when the guns cost several thousand pounds and were considerably the worse for wear after a few hundred rounds, it became a very important matter to reduce erosion to the minimum, obtaining at the same time the same velocities and pressures. He believed that in that direction steps were now being taken.

Mr. Perks. Mr. G. W. Perks remarked with regard to the incorporating machines, Figs. 1, Plate 2, it had been mentioned that at Waltham Abbey electricity had been generated on the belts, but he had been unable to detect it at the Hayle factory. With regard to the main press for the large size of cordite, it seemed to act very well with the exception of one point, which a previous speaker had alluded to, namely, the speed at the ram. If that could be governed, it would be a very great advantage to cordite. The paste might be hard or it might be soft; if it were soft, the ram necessarily acted with greater speed, and a higher speed resulted, and, consequently a thinner cord, which might easily be beyond the specification, so

that a regular advance was of great consequence in the manufacture of cordite. An accumulator certainly might be an advantage in working with the hydraulic press. If such an apparatus were used as an adjunct, he thought it should be of sufficient capacity to be equal to the contents of the press with which it was worked. If smaller, the accumulator became simply an exaggerated relief-valve. With regard to the small rifle-press, he could not but admire its arrangement and mechanism. Those who had watched it must have been struck with the skill with which it worked, and certainly it did great credit to its designer. The cutting-belt, for the larger sizes, he thought, however, wanted a little consideration. The cords were carried over an endless belt, with knives projecting from the face, and consequently the cords lay with a slack; there was nothing to guide them, and they did not ride parallel by any means. The result was that, although they passed between knives fixed at a regular distance from each other, the cords, when they passed under the roll which made the cut, might be of various lengths, varying perhaps possibly 1¼ inch. There might be only 1¼ inch difference between the two cords, but it was a very great difference, especially as manufacturers had now to work within a few grains, more or less, in the weights of the cords which were cut off. The specification did not allow a greater variation in the weight of any two cords than a very few grains, and, consequently, it was a matter of great importance that the cord should be cut off very nicely. With regard to the loading press, he had noticed that occasionally, in putting the charge home, if the machine was not carefully worked, the charge seemed to be drawn back, and a short charge was given. It might be that the time of the two grips in the machine in question was not properly regulated for use. The matter of air-bubbles in cordite had been spoken of. As a matter of fact, if a stick of cordite which showed a number of air-bubbles was taken, it was found to be practically solid; it might be that there had been air between the main body of the stick and the skin, but as the cordite came from the die, the air was expressed, and nothing but a solid stick of cordite resulted. It had been stated that at Woolwich sticks which showed air-bubbles and sticks which did not show air-bubbles had been fired for comparison, the result being practically the same. Lumps of paste could not be placed into a cylinder to fill it entirely; there must be a certain amount of air, but that air escaped past the plunger or came away with the cord, but not in it, making a noise like a slight explosion. To illustrate that, he might say that when the National Explosive Company first started their cordite Mr. Perks.

Mr. Perks. machinery, as an old manufacturer of explosives he was cautious. In gunpowder works, when runners had been dressed, and before starting them again, a preliminary run was made on charcoal instead of an explosive mixture. With cordite it occurred to him that a safety trial of the machinery should be made also, and he thought that dough would be a very good substance to put through. He charged the cylinder with the dough, and the result was astonishing. Had it been cordite which was being passed through, he did not think a man would have remained in the building; the air coming through with the dough made sounds like a batch of never ending crackers. As long as any paste was in there were reports like a *feu de joie*.

Mr. Thomson. Mr. J. M. Thomson observed that the Author had referred to the original press which was used for squirting the rifle cordite. He might say that it was constantly in use. The same press was used as at the commencement of pressing the cordite, and that, he thought, reflected great credit on those who first designed it. It worked about as well as the other presses which were now used. Reference had been made to one or two slight explosions which had taken place in a small rifle-press ramming-machine. As had been said, there was apparently no danger in it, because there was only a sharp report, very slight, and a good deal of the cordite paste was thrown out of the mould. But in gathering up all the fragments, practically no difference could be found between the weight of the charge which had been gathered up and that which was usually put into one of those moulds, so that the explosion must have been very local indeed. But it was not pleasant to have that recurring perhaps four or five times, at intervals of from 3 months to 9 months. Several experiments were therefore tried, to put an end to those slight explosions. First, it was suggested that it was the rapid travelling of the ram that was brought down too quickly upon the cordite, the air in the cordite becoming compressed so quickly that it generated sufficient heat to ignite a local part of the cordite, and so cause a slight explosion. To obviate that, the foreman of the cordite was caused to turn on the cock of the rammer, so that the ram travelled at a certain speed. The cock was put in a box so that no man could increase the pressure, and the rate of travelling was thereby kept at a more definite speed. On the table round about the rammers, small pieces of cordite were apt to become dry, and in sweeping them up, the men sometimes put them in the mould, and it was thought that they were liable to explosion from friction through being dry. Orders were therefore given

that that dry material should never be used in the mould, and it was now at all times mixed with acetone and incorporated again before it was used. Another thing to which attention had been directed was the grit. It had been said that the scoring was due to grit in the cordite, and possibly that was so. To get rid of that grit, which certainly was present in the cordite, the gun-cotton was naturally looked to as the source. Raw cotton did contain a good deal of grit, which of course in passing through different stages of manufacture into gun-cotton was mixed with the nitro-glycerine, and so it got into the cordite. To obviate this, various traps were arranged after the gun-cotton was pulped, and with other arrangements, the grit was reduced to a very small quantity indeed. At one time, he thought he was right in saying, out of 80 tons of cordite about 4,000 grains would be obtained. It locked a large amount, but if it were calculated out, it was a very small percentage indeed. After those traps and other things had been arranged to stop the grit, it was found that it was reduced to not more than 400 grains. If his memory was correct, he thought that at the last monthly weighing it was found to be about 200 grains. That might have been an exceptional case, but at any rate, it had been reduced from 4,000 grains to 400 grains. Since those three things had been done—to what cause it might be traced he did not know, perhaps all three—there had never been any explosion with the small ram, and it was now nearly 3 years since there had been one of those slight explosions. The machinery worked very well. He was inclined to think that many of the difficulties which had been referred to could be overcome by the men becoming acquainted with the machinery and getting better into the way of it. He knew the working of the small press was at first a very great difficulty indeed; the cord coming out so quickly was very liable to break; but now, after experience, it could be worked quite easily, almost without a single break. It was beautiful to see the way in which those presses worked, and the way in which men could now cope with the difficulties which they felt so much at first. With regard to the other presses, he thought the hydraulic presses could now be worked quite well. There was very little difficulty now with them. The rate of bringing down the plunger had also been attended to; it was brought down at a definite speed. The superintendent of the factory had caused an indicator to be erected close by, that the man might see at what speed he was bringing down the rammer of the hydraulic press, and so arrange it that he never brought it down

Mr. Thomson.

Mr. Thomson. too quickly. The reason was that the hydraulic presses, such as had been mentioned by the Author, were surrounded by rope mantlets, so that the man could not see the speed of travel.

Mr. Lloyd. Mr. R. S. LLOYD noticed that many speakers had mentioned the trouble arising from the presence of air in the die whilst pressing. A very simple method for removing it was used in many hydraulic die-presses, such as those for pressing tea and camphor, which consisted of perforating the upper die and putting under it a diaphragm also perforated, of zinc or brass, and a thin coating of swan's-down. This method allowed the air to pass through the top die without letting the substance which was being pressed come through and consequently prevented blistering afterwards.

Mr. Trench. Mr. G. TRENCH observed that the factory was designed by the Author and had been passed by the Government inspectors. With respect to the thickness of the walls, he did not think that they were thinner than they should be, or Sir Vivian Majendie and his colleagues would not have passed the buildings. With regard to keeping air from the dough there was no question that the freer the dough was from air-bubbles the better, and he thought it important to get the stuff free from air before the cord came through. The cordite was worked in the incorporating mills perhaps longer than had been necessary, but by doing so he thought the air was practically eliminated. Cordite was being made at 0·03 inch and up to 1 inch in diameter, and to all appearance it just went through the die, and after drying and cutting up it appeared to him to be all that could be desired. Some samples that he had had analysed had proved perfect in every way, and those had been made in different stages by the machinery, according to the plan shown on the wall. He thought the sooner that the machinery worked entirely by hydraulic power the better, but he could not understand the way in which a previous speaker intended to do it. He certainly thought that if hydraulic power was used alone, there would be an advantage over having oil running about. Water must be better than the oil which might be running about in the gear.

Mr. Smith. Mr. H. MELVILLE SMITH wished to say a word to redeem the character of the little machine which had been referred to by Mr. Ristori. It appeared that the machines referred to in the Paper loaded 6,600 cartridges in a day of 8 hours. It was being worked at the present time at 8,000 in 8 hours, and 10,000 in 9½ hours. It was curious how that extra 2,000 came up in the odd hour and a half, but it was a fact. Although the filling had nothing to do

with the manufacture of the cordite, the air-bubbles, or the occluded air, or whatever it might be, were felt when they came to the machine, because there was a tensional strain on the cordite in drawing it through, and it broke where the air-bubbles occurred. With regard to Mr. Perks' remarks about the machine not working very nicely, twelve of the same machines were being worked on the same cordite and were doing remarkably well. In the last ten million not a single short charge had been recorded. Mr. Smith.

Sir WILLIAM ANDERSON, K.C.B., Vice-President, observed that the virtues of cordite had been so fully dwelt upon by Sir Henry Brackenbury that he would say no more on the subject; he would like, however, to mention that the explosive now manufactured was the twenty-eighth combination tried by Sir Frederick Abel and his Committee in 1889. The nature of the ingredients and their relative proportions then fixed had never been deviated from in the slightest degree and were the same for every size and form of cordite now made. This, from a manufacturing point of view, was a very important feature, as the same "dough" was available for squirting into any sized cord. He was somewhat surprised that none of the speakers had alluded to the recovery of the acetone used as a solvent to the two chief ingredients of the explosive, because he still occasionally received proposals from inventors to effect this object. It was not overlooked by Sir Frederick Abel, because acetone was at the time a very expensive ingredient, costing as much as £224 per ton, and therefore the first reel-drying apparatus was contrived so as to condense the acetone vapour. It was found, however, that the rate of drying had to be slow in order to prevent an impermeable skin forming on the sticks and impeding the escape of acetone from the interior of the mass, and this condition was incompatible with the collection and condensation of the vapour. For the same reason cordite was not dried, like gun-cotton, by a current of warm air, but by the almost stagnant air of the stoves kept at a proper temperature by means of warm-water pipes. The price of acetone fell in 1891 to £187 per ton, and was now only about £50 per ton, so that there was no longer the same object in attempting to recover it, although the supply was almost dependent on Germany. Acetone was the product of the distillation of acetate of lime, which again was produced by the combination of pyroligneous acid, resulting from the distillation of wood with lime. As there was at the Woolwich Arsenal a large quantity of waste wood produced in the saw-mills and woodworkers' shops, he had established an Sir William Anderson.

Sir William Anderson. acetone factory there and hoped before long, with the aid of some private firms in England, to become independent of foreign supplies. The rate of drying and the extent to which it was carried had an important bearing on the ballistics of cordite, especially with regard to the narrow limits within which the muzzle velocities and pressures must fall. Thus, in size 30 used in the 6-inch quick-firing guns and in several others, in a muzzle velocity of 2,200 feet-seconds, there must not be a greater variation than $\pm$ 25 feet and a maximum pressure of 16 tons per square inch chamber pressure. But this variation depended on the state of the gun, on the weather, and on the make-up of the cartridge, and was by no means easy to limit, even with the aid of corrections made by comparison with a standard lot fired at the same time. Again, the density of the charge had much to do with the regularity of ballistics. The normal density aimed at was a chamber capacity of 80 cubic inches to the lb. of cordite; but in old guns, adapted to the use of the new explosive, this was widely departed from. Thus in the 4·7-inch and 6-inch quick-firing guns the density was 54 cubic inches, and in the magazine rifle it was as high as 41 cubic inches. The greater the density of loading the greater was the possible pressure of cordite gases. Thus at 80 cubic inches per lb. the pressure might rise to 30 tons per square inch; but at 54 cubic inches it might be 48 tons, and at 40 cubic inches 70 tons, so that the slightest hesitation in the shot, a high driving band, or increase in rate of burning, would send up the pressures the more rapidly and higher, the greater the density. With regard to Mr. Ristori's remarks on the speed of manufacture, he would say that pressing the machinery unduly was not permitted in the Royal factory, as it was not considered compatible with safety and good work, nor was it necessary in order to produce the explosive economically, because the cost of that made at Waltham Abbey was, at this moment, a little less than half the contract price paid to private firms. The diameter of the cords had proved a very important factor in attaining the required ballistics, but the correct size was not easy to attain in practice because the cords shrunk a good deal, not always regularly, in drying, and the ultimate diameter depended upon the state of viscosity of the "dough"; that, again, depended on climatic changes and on the time taken to deal with a charge, so that very great care and vigilance had to be observed. The length of the cords was only of moment with reference to the making-up of the cartridge. The fact, often observed, that an actual, and even violent, explosion of a small quantity of "dough"

in the presses did not fire the whole charge, was very remarkable. Sir William Anderson. A cord laid on a rail and struck with a hammer would explode immediately under the hammer, but the pieces on each side would not fire. No dust was produced in the manufacture or handling of cordite, hence precautions in the structure of buildings and in the disposition of machinery which were obligatory in the manipulation of dusty explosives were not necessary in the production of cordite, though the most stringent precautions had to be observed in the handling of dry gun-cotton and in the production of nitro-glycerine.

Mr. Anderson. Mr. E. W. ANDERSON, in reply, referred to a letter he had received from Colonel Sir V. D. Majendie, Chief Inspector of Explosives to the Home Office, in which he stated that he had in several instances found that electricity was developed by belts in the manner described in the Paper. In one case the trouble had been cured by the use of an india-rubber belt, and in another by the use of Rossendale hair-belting. He considered that this generation of electricity constituted a real danger in explosive factories, and thought it might account in some instances for accidents, the cause of which was obscure. He confessed that when he wrote the words relating to the "mixture or solution" of nitro-glycerine and gun-cotton, he felt he was treading on delicate ground, as he believed this was a debateable point in the minds of chemists. His own impression was that the gun-cotton of which cordite was made, though consisting mainly of the insoluble variety, also contained a small proportion of the soluble in its composition; and, in that case, he thought the paste would be, though mainly a mixture, partly a solution. In his statement that the "paste" was not an easy material to explode, he was guided simply by the experience which had been gained concerning the matter. Nitro-glycerine could not be carried about in its ordinary condition without grave risk, and indeed he believed its transport, in England at any rate, was absolutely forbidden. He understood also that it was not considered advisable to convey gun-cotton about unless it was combined with a considerable proportion of moisture; whereas the mixture of nitro-glycerine and dry gun-cotton could be transported by rail, or other means, without fear of mishap. The explanation given of the possible cause of the ignition of the cord in the original press, on the two occasions mentioned in the Paper, was very interesting. He had always thought it was simply the result of the friction due to the great speed at which the cordite was forced through the die. As regards the relative liability to accident of the screw- and hydraulic-

Mr. Anderson. presses, he based the opinion given in the Paper simply upon actual results. If explosions did occur with the screw-presses, nobody was aware of them, whereas several had happened in the various hydraulic-presses, and had done a tangible amount of damage to the machinery; so that, as stated in the Paper, at Waltham Abbey it was considered desirable to enclose these latter with mantlets. The hydraulic-press, shown in Fig. 4, Plate 2, was not his own design; and, as soon as his firm had to construct presses of this type, he decided to use three columns instead of two, in order to give greater stiffness. The pedestal for the cylinder was supported upon shorter and stiffer pillars, and the ram head was also guided upon the three main columns; so that, provided the cylinder was put properly into position after charging, he did not think that any undue side friction of the plunger in the cylinder could possibly arise. No doubt it would be well to make the water-pressure adjustable, and this would involve no great difficulty; but his own opinion was that the better plan would be to devise an accurate method of controlling the speed of the press independently of the pressure altogether, in which opinion he was glad to see that one of the subsequent speakers, Mr. Perks, coincided. As to the use of mild steel in cylinders, it certainly had been adopted in the larger sizes with success, and one was shown, made of this material, in Fig. 4. The object of using it was for the sake of lightness in cases where the cylinders had to be shifted about. Although it did not answer well for the small presses, where the pressure on the dough was high, it seemed satisfactory in the large presses, where the pressure was much less. The question raised about the thickness of the partition walls in the factory, shown in Fig. 10, Plate 2, had been already answered by Mr. Trench, who stated that the walls of his factory were made 9 inches thick and were accepted by the inspectors. He pleaded guilty with regard to the doors; they should open outwards, but he had overlooked the draughtsman's error in showing them as they were. He thought it would have been interesting if Mr. Ristori had given some general description of the machinery he had used, and the form of the explosive produced by it, so that a fair comparison might be made between the two processes, which was otherwise impossible. The manufacture of cordite had been cautiously developed, so that the resulting product might be maintained of the highest possible quality and uniformity, and risks of accident avoided. Speeds had been increased, and the production had been cheapened; but he did not consider that finality had been by any means necessarily reached

Mr. Anderson.

yet. He thought any radical modification of the present process, with a view to expediting and cheapening it, would be sure to interfere with the high standard of safety and quality now obtaining. The same principle applied also to the filling-machines. It would not do to run any risk of spoiling the remarkable accuracy with which the rifle cartridges were now charged, the importance of which could not be over-estimated. No doubt it was desirable to avoid gearing as much as possible in explosive machinery, but in the cordite manufacture no harm had ever resulted from its use; and, as already pointed out, the geared machines seemed to be absolutely safe, whereas those that had no gearing were decidedly liable to accident. The reason for the increase of weight in the pressing cylinders, to which Mr. Pollitt had referred, was the fact that the earlier cylinders made were too weak at their upper ends. As first made the metal was reduced in thickness at the top for the sake of lightness, as the pressure in the cylinder would not be so heavy at the commencement of the stroke as it would be later, because, the material being put in loose, the first portion of the stroke would be occupied simply in consolidating it. Apparently, however, this reduction had been somewhat overdone, and the cylinder seemed to be weak, so that the next ones made were increased in thickness. These cylinders were made in phosphor bronze, and it was thought the pressures in them would be too great to work well with mild steel. The interrupted screw for the cylinder covers was abandoned, because it was found in practice that the dough was liable to get into the interruptions and between the threads. The ends of the sections of threads were also liable to be damaged by careless putting together; and, as in practice no time was found to be really saved by this construction, the continuous thread was finally adopted. He had had no experience with the Krupp method of manufacture (though he had seen the design of press referred to by Mr. Pollitt), and therefore he could give no information as to the actual results obtained with it. It appeared to him, however, that the bugbear of air-bubbles existed more in fancy than in reality, and that cordite quite free from them could be made by the process described in the Paper by using ordinary care. With regard to the drums of the single-strand reels, perforated zinc had been used in these for facilitating the drying process; but the Waltham Abbey authorities had found that apparently the perforations were not necessary, and they had latterly used solid brass sheet, because the reel was thus somewhat stronger and less liable to get damaged. It was preferable to dry cordite slowly, as it was

Mr. Anderson. more effectively performed. Hence at Waltham fans were not used, as they would accelerate the process; the theory being that quick drying soon made the surface of the cords hard and prevented the acetone from getting out of the interior, so that an apparently dry piece of cordite might still retain a considerable portion of the solvent. Slow drying avoided this action. He had been gratified to hear Mr. Rigby's confirmation of the great accuracy of the rifle ammunition. He agreed as to the general principle enunciated by Mr. Rigg of designing machinery, but special machines required special treatment, and he believed that in cordite machinery it was preferable to keep the gear at the top, as there was then no chance of small pieces of the explosive getting into the moving mechanism, which might happen if it were underneath the pressing cylinder. Apparently no great harm was likely to result even if it did, but it was always better, where possible, to be on the safe side. Mr. Kraftmeier's observations threw considerable light on the air-bubble question. He could not understand how Mr. Perks obtained so much difference as 1½ inch in a 14-inch length. (Mr. PERKS stated that he had referred to a 24-inch length.) That made it a little more comprehensible, but he had never heard that such difficulties had been experienced at Waltham Abbey, and the lengths were always kept within the allowable limits. He thought that the leather belts might alter or stretch, and thus cause differences that should not otherwise exist; but this could be obviated by the latest plan of using belts of flexible sheet-steel, in which such variations would be inappreciable. He thought the filling-machine Mr. Perks alluded to could not have been in proper adjustment; that was, one clamp must have opened before the other was closed, and thus the cordite was left for an instant free, and any slight tension on the rope would cause it at once to draw back through the clamps; or it might have been that one or both of the clamp levers were stiff and did not close down properly to grip the cordite; or the slide might have been stiff from congealed oil or dirt and the weight on the pedal lever might not have been sufficient to carry it back right against the stop. There was abundant evidence that the machine was exceedingly correct in its work, but of course it must be kept in proper order. The explanation given of the air-bubbles in cordite not being really air-bubbles, but rather laminations of the material, must be a correct one, judging by the results that had been obtained and to which allusion has been made. Mr. Thomson's observations were most interesting, and it was encouraging to hear that with proper experience and care even such explosions as

had occurred might be prevented altogether. He was gratified to have Mr. Melville Smith's testimony, both as to the efficiency of the filling-machines and the speed at which they could be worked. Mr. Anderson.

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18 January, 1898.

Sir JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S., President, in the Chair.

The evening was occupied in the discussion upon the Paper "The Machinery used in the Manufacture of Cordite," by Mr. E. W. Anderson.

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25 January, 1898.

Sir JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S., President, in the Chair.

(*Paper No. 2996.*)

"Reservoirs with High Earthen Dams in Western India."

By WILLIAM LUMISDEN STRANGE, Assoc. M. Inst. C.E.

RESERVOIRS in India are required to store water for irrigation as well as for the supply of towns. For the former purpose the sites are generally selected in elevated places at the head of fertile valleys; for the latter, as near as practicable to the population to be served. The storage-capacity required for the former class of reservoirs, although it is, as a matter of economy, designed for only 1 year's supply, as a rule very greatly exceeds that for the latter, even providing, as such works should in India, a sufficiency for 2 years' consumption. Hence the size of the dams for irrigation reservoirs, or "tanks," as they are locally called, is usually much larger than that for town-supply works.

Irrigation reservoirs may be divided into two classes, according to their situation : (*a*) Ghaut-fed, with an assured annual replenishment, and (*b*) Eastern, with an uncertain annual replenishment. The chief objection to reservoirs of the first class is that they are generally some distance above the canals, and thus there is considerable waste of water in transit. To the second class the chief objection is their precarious supply; but, on the other hand, they are situated conveniently to the distributing-works.

Rainfall.—In the Bombay Presidency the rainfall is practically confined to the "rains," lasting from the beginning of June to the middle of October, and, in the southern portions, to the early part of November. In amount, it varies between 300 inches annually at Máhábleshwár, the highest station in the Western Ghauts, to less than 20 inches in what is known as the "famine zone," distant between 50 miles and 100 miles east of the main watershed. The months of heaviest rainfall are generally July (due to the south-west monsoon) and October (due to the north-east monsoon). The

other months of the "rains" have a comparatively small fall; the rest of the year is generally rainless, and is very seldom productive of replenishment to reservoirs. Construction work is limited to this last-named period of 7 months. Bombay is fortunately seldom disturbed by cyclones, but in Bengal and Madras there are occasionally violent cyclonic storms.

Climate.—During the "rains" the climate is cool but fever-producing. The "cold weather" succeeds and lasts till the middle of February; it is cool and bracing, but fever-producing, especially at its commencement. The "hot weather" closes the working year, and, although it is sultry, is, on the whole, the most healthy period except when outbreaks of cholera occur.

Physiography.—The Bombay Presidency comprises four main physical divisions:

(*a*) To the north is the practically rainless plain of Sind, the irrigation of which has been developed by several canals of the largest size drawing from the Indus.

(*b*) To the south of (*a*) is the level and hot fertile plain of Guzerát, where the rainfall is generally well distributed, and large irrigation storage works have, in consequence, not been recently constructed. South of this again is the Presidency proper, which is divided into—

(*c*) The Konkán, which lies between the sea and the Western Ghauts; it has a rainfall, abundant throughout, and excessive near the watershed, and artificial irrigation is not practised to any extent; and

(*d*) the Deccán, which is the tract to the east of the Ghauts. Here the rainfall is capricious, and, to the east, very scanty; it is in this portion that almost all the large storage reservoirs have been constructed, and it is this area which will chiefly be considered in this Paper.

Geology.—With the exception of the southern part, where metamorphic rocks occur, the whole of the Deccán consists of the Deccán and Málwa trap formation. The trap exists in all varieties, from the hardest compact rock to schistose strata, which, in the course of ages, have decomposed first to "murum," a friable, stony material, and then to various argillaceous soils, of which the best known and most widely distributed is the black "cotton soil." The rock is finely crystalline and heavy; the better varieties, especially the boulder rock, are practically unchangeable, are very hard to work, and break with a conchoidal fracture. There are others which at first sight appear nearly as durable, but, in the course of a few seasons, and occasionally in a single

year, decompose under the extreme meteorological conditions into friable and clean "murum." They are distinguished by a less crystalline and duller appearance, and are occasionally traversed by lighter-coloured bands, or by quartz veins. Great care is necessary to discriminate between the useful and the useless varieties, for both are hard and sound when first excavated. The black "cotton soil" has been chiefly used for the construction of the older dams in consequence of its abundance and watertightness. It is, however, by itself, a treacherous material, absorbing water easily, and cracking when dry; its frictional resistance to slipping is small, owing to its unctuous character and freedom from binding grit.

Hydrology.—The surface of the country, especially in the hilly parts, is veined by numerous watercourses or "nullas." During heavy rain these become torrents; on its cessation they quickly dwindle to small rills and soon afterwards dry up. As a general rule, except for a few days in the year, they are dry.

As the streams increase in size so does their violence diminish and the duration of their supply increase, but, with the exception of a few rivers of the largest size, they all become torrents during heavy rain, and few have a perennial flow of even small amount.

Materials.—The materials required for dams and their subsidiary works, viz., stone for building and pitching, argillaceous soils and "murum," metal and "kankar" (nodular hydraulic limestone), are generally abundant and close at hand; otherwise, where the works are situated in out-of-the-way localities, it would not be feasible to construct them economically.

Labour.—Dams are constructed almost entirely by manual labour, large numbers of men, women and children being employed for this work. On some of the large famine-works some 20,000 persons have been engaged at one time. The soil is loosened by pickaxes, scraped with large hoes into basin-shaped iron baskets, holding about $\frac{1}{3}$ cubic foot each, by other men, and the loaded baskets are carried to the site as head-loads by women and children. The bulk of the labour is furnished by the poorer agricultural inhabitants of the locality, and the numbers are thus largely affected by the character of the season. These people work in gangs of between twenty and fifty each under a headman, and are most usefully employed on task-work. There are also, but in much fewer numbers, gangs of trained labourers, who wander about the country for work; these gangs prefer to be as independent as possible, and almost invariably work by piecework. In addition to human labourers, pack-animals—donkeys,

oxen and buffaloes—have always been employed by the natives. More recently carts, and, still more recently, small portable tramways and light trucks have been used; these last-named are especially useful, cheap and expeditious where the lifts are not too high.

Old Native Works.—There are many small native "tanks" in Guzerát, and still more in the south of the Deccán; these vary in size between mere ponds, for the irrigation of a single field, and reservoirs covering 500 acres. The dams of the last-named are long, but none are more than 30 feet in height. In the Madras Presidency there are thousands of such tanks, which are not reservoirs, in the usually accepted sense, but are only intended to tide over breaks in the monsoon so as to enable the rice-crop to be grown. The natives have, however, left examples in many parts of the country [1] of stupendous works of this class, one of which is the ruined [2] Madág tank, on the border-line between the Dhárwár Collectorate (south of Bombay Presidency) and Mysore, which is believed to have been constructed during the Vijayanagár dynasty, A.D. 1335–1570. The dam occupies a splendid natural position between two spurs, averaging 800 feet apart. Its height is 100 feet, its top width 400 feet, and its base width over 1,000 feet. The lake must have had an area of nearly 40 square miles.[3]

These native constructions, being formed carefully by small head-loads, and being fairly consolidated by the treading of animals and labourers, have stood well, and when formed of suitable earth have become in the course of time extremely compact. They were constructed without puddle trenches or puddle walls, and in consequence even the smaller dams leak to a certain extent, although their beds are silted up. The chief cause of failure was the insufficient provision for the discharge of floods.

The modern construction of Indian reservoirs will now be described, each main subwork being separately dealt with.

Puddle Trench.

The puddle trench is excavated along the centre-line of the dam, and is taken down with a base width of between 6 feet and 10 feet, and with as steep side-slopes as possible (for timbering is not resorted to on account of its expense), well into sound

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[1] Minutes of Proceedings Inst. C.E., vol. lix. p. 53.
[2] *Bombay Gazetteer*, vol. xxii., Dhárwár.
[3] For other examples, see *The Engineer*, vol. lxiii. p. 189.

retentive clay, or, at least, 1 foot into sound trap rock.[1] The puddle mixture is formed of three parts of black or other argillaceous soil and two parts of sand. The bottom layer, about 1 foot thick, is formed of carefully kneaded balls of the mixture, which are thrown on to the bed and trodden on it to form a watertight junction. For the subsequent layers the mixture is inserted dry, is well watered and worked up by treading, each layer on completion being covered by the dry material of the next one to prevent its being cracked by the sun. The puddle is carried up 1 foot above ground to key into the body of the dam.

In excavating the puddle trench, the greatest care should be taken to avoid all sudden steps in its longitudinal section and vertical sides in its cross section. On both sections it is essential that the trench should be bounded by slopes. The material being compressible, a step would tend to cause a crack above it, while a vertical side, or, still worse, one sloping downwards away from the centre line, would tend to the formation of a hollow space. Timbered trenches, owing to their vertical sides, are objectionable for puddle work on this account.

River Crossing.—In the river-bed additional precautions are taken to prevent leakage. The main puddle trench is diverted about 20 feet upstream, and a concrete trench, about 5 feet wide, is constructed on the centre line of the dam, across the river-bed and well into its banks, and is run at each end into the puddle trench, which is thickened to receive it. The practice of having two trenches at the river-bed crossing appears open to the objection that, assuming the trenches are efficient, the result is at the centre of the highest section of the dam there must be an area—that between the trenches—of sodden foundation into which a certain amount of water must leak, and from which it cannot easily escape owing to the presence of the down-stream trench. Earth through which water percolates is much sounder than that in which water stagnates; probably, because in the former case the moisture passes between the ultimate solid particles of the soil, while, in the latter, they are in a state of solution. The presence of this sodden area must tend to cause bulging of the foundation and settlement of the superstructure. The more expedient plan would be to widen and deepen the main central trench at the river crossing, and, if necessary, to have in it a central concrete trench.

Concrete and Puddle Trenches.—In England puddle is relied upon

[1] Minutes of Proceedings Inst. C.E., vol. lxxvi. p. 288.

to make the concrete beds and walls[1] of service reservoirs watertight. On the other hand, it is the practice of some engineers[2] to abandon a puddle trench for one of concrete. This is probably because narrow-timbered trenches are used, and the concrete can be rammed watertight to fill the whole space. An objection to the use of concrete is that, if for any reason a settlement crack should be formed, or two layers be not in watertight union, a permanent leak will be set up. In the case of puddle such faults would tend to remedy themselves by the compression of the material. Allowing that well consolidated concrete is more watertight than an equal thickness of puddle, it remains to be seen if thicknesses of the two materials of equal cost would differ so much in efficiency. In India concrete would cost nearly eight times as much as puddle, and although the latter is not so efficient as English puddle, still the much greater thickness economically permissible renders it as safe to use as concrete. Moreover, in the open puddle trenches as excavated in India, it would not be practicable to construct cheaply a thin, watertight concrete wall. When keying a trench into solid rock a narrow concrete trench may be substituted with advantage for puddle. The depth to which that key is necessary is a matter for consideration, as care should be observed not to fissure the rock by blasting.

Position and Dimensions.—The centre line of the dam is, no doubt, the best position for the puddle trench to ensure a symmetrical settlement over it and to interpose a sufficient extent of dam and natural soil to impede the percolation of reservoir water. Otherwise, for the sake of getting as much of the base of the dam as dry as possible, it would be advisable to place it somewhat upstream, say to the inner edge of the upstream third of the base. Fortunately, in Western India good watertight foundations can be usually met with at a reasonable depth, and the unstratified nature of the geological formation is also a favourable feature. At the same time it may be necessary to consider to what depth a puddle trench should be sunk when a perfectly satisfactory foundation for it cannot be found. At the Cant Clough[3] reservoir for the Burnley Corporation, the concrete trench was sunk between 160 feet and 190 feet, and even then did not reach perfectly watertight strata. It is very

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[1] Minutes of Proceedings Inst. C.E., vol. lxxiii. p. 1.
[2] *Ibid*, vol. lix. p. 61.
[3] *Ibid*, vol. lix. p. 61; and *The Engineer*, vol. lxiii. p. 13.

doubtful if even such a great depth would entirely prevent the passage of water although it would be useful in affording, on the downstream side, more natural means of drainage for the infiltering water.

The rate of filtration of a soil depends upon its porosity, which governs the frictional resistance to flow, and the slope and length of the filamentary channels along which the water may be considered to pass. It is evident, therefore, that the direct rate of infiltration in a homogeneous soil must decrease from the top to the bottom of the puddle trench. The best section for a puddle trench is thus a wedge, such as an open excavation would give. It is true that the uppermost infiltering filaments, when stopped by the puddle, will endeavour to get under it, but a depth will be eventually reached when the frictional resistance along the natural passages will be greater than that due to the transverse passage of the puddle trench, and it is when this occurs that the latter may be stopped without danger, as the filtration to it will be less than that through it. This depth requires to be determined in each case, but in fairly compact Indian soils 30 feet will be a fair limit.[1]

Where a sound clay bottom can be met with, the trench need only be sunk 10 feet into it with a minimum total depth of 20 feet from the surface. The puddle trench should be sunk through fissured rock and at least 1 foot into sound rock where this is met with at a smaller depth than 30 feet, and is not overlain by a layer of 10 feet of good sound clay. In all cases it should be recognised that the maximum subsoil flow occurs along the top of the impermeable stratum, and care should be taken to intercept it by keying the trench well into the stratum. This may be best done in the case of hard soils by forming a concrete trench below the puddle one. Where the geological formation is stratified, these depths may have to be exceeded; but it is a question if it is necessary to go to a great depth in order to endeavour to intercept small subsoil flows. Also, where the dam is situated on a narrow ridge of porous soil, the depth would have to be increased; but, as a rule in Bombay, such ridges have a naturally good rock foundation.

In India the inflowing water replenishing the reservoir is

[1] Mr. David Gravell cites the opinion of Sir Robert Rawlinson, that 30 feet depth of puddle trench is sufficient if a thick bed of concrete is placed at the back with a well for collecting water and a pipe leading this off to the downstream side, as was done in the case of Yarrow Dam; *The Engineer*, vol. lxiii. p. 189.

always heavily charged with silt, so much so that the storage capacity of even modern works has been seriously diminished by it. This silting up of the beds very sensibly diminishes the tendency to leakage, although it would be wrong to entirely depend upon it, as is evident by the old native reservoirs for which no puddle trenches were constructed. Even the smaller ones of this class are more leaky than is desirable. The best modern example of the tendency of reservoir beds to become waterproof is the Muchkhundi Tank, Bijápur Collectorate, formed by a masonry dam on a vertically schistose formation. This, at first, held but little water, but it has annually become more watertight, and the loss from leakage is now but small, although the work has only been completed 12 years.

In all well-constructed modern dams the actual value of the loss of water by leakage through the subsoil is not sufficient to justify the cost of expensive measures to lessen it, and, in most cases, it would be comparatively easy and cheap to pick up the escaping water lower down the stream and utilise it for irrigation.

The width of the trench is a matter of importance. A base width of 10 feet should be taken as the minimum allowable, and a greater width, say up to 14 feet, is desirable, so that rollers may be used to effect the maximum amount of artificial consolidation. Where the dam is high the base width may be made equal to one quarter of the full-supply depth of the reservoir at the point considered. The bed of the trench should be roughened so as to prevent the formation of a definite line of subsoil flow. The side-slopes of the trench should be as steep as practicable, but not steeper than $\frac{1}{4}$ to 1. With such slopes and a base width of 14 feet, a trench 30 feet deep would have a top width of 29 feet to resist the maximum rate of direct infiltration. It is better and cheaper to rely upon a comparatively shallow, well-drained puddle trench than upon a narrow and deep one, as the largest amount of subsoil leakage generally takes place near the surface.

In Bombay dams the puddle trench is only carried as far as the high flood-level margins of the reservoirs. As this is usually 5 feet or 6 feet above the full-supply level and the natural slopes of the ground are flat, this extent of trench is sufficient, under the conditions in force, and the arguments for not greatly deepening the trench apply still more forcibly to not increasing its length.

The puddle material is usually carried up a little above the surface of the ground in order to cut off the flow along the base of the dam. This extra height should be constructed at the same

time as the dam on each side of it, and should be rolled and consolidated with it, the only difference between the parts being that of the material employed in them. If the completion of the puddle trench has to wait for the dam, its upper surface should, at first, be kept at ground-level for convenience of work till the dam can be raised, and if any cracks occur, the temporary surface should be cut out and re-made.

Puddle walls in the dams themselves never occur in Bombay practice, for reasons which will be given later.

Filling.—The material of the puddle-trench filling should be the most retentive clay procurable. A mixture of more permeable material, such as "murum," can only be effective in preventing shrinkage and the formation of cracks. The layers of puddle should, however, be so quickly formed on each other that the sun should have no time to act in causing the material to crack. It is true that an admixture of impermeable stone with the clay, if it can be ensured that each particle of aggregate is separated from the rest of the matrix, may be watertight; but the mixture would not be homogeneous, and the water would have a shorter course in passing from one stony particle to another than it would have through solid clay. When once the puddle trench is under the dam it is under practically settled conditions and cannot well crack. It will, on the contrary, tend to be compressed, and if water is absorbed from it by the subsoil, the compression will be aided and the material improved.

Experiment[1] has shown that a good natural specimen of clay when dried lost 25 per cent. of its weight, and 10 per cent. of its bulk; it then became extremely compact, and, if not allowed to expand, offered great resistance to the passage of water. A dried specimen of this clay reduced to a fine powder absorbed about 75 per cent. of its weight of water, and allowed of free percolation. When this powdered clay was pressed into a tube 8 feet long and 3 inches in diameter it absorbed 35 per cent. of its weight of water, but there were no traces of filtration through the tube. The compressed particles of clay, in absorbing the water, expanded so as to become watertight. On a large work it would not be economically practicable thus thoroughly to desiccate clay, nor feasible to consolidate the whole dry mass. The experiments show, however, the advisability of using no more water in the puddle trench than is necessary to produce a compact substance by rolling. The further compression of the trench-filling should be

[1] *The Builder*, vol. li. p. 400.

given by the superincumbent weight of the dam, which should be allowed to act for as long a time as possible before the reservoir commences to fill, so as to prevent filtration through the green material. In a wet state clay reaches its extreme point of expansion, and, when thus exposed to the action of water, filtration must take place between the separated particles. Clay is, moreover, so retentive of water, that, if once soaked, it will be long before it parts with the excess of moisture; hence the greatest care should be taken during construction to use the minimum amount of water.

Drainage.—Notwithstanding all precautions, some water will certainly pass through the puddle. Its amount may not be great, but its effect in soddening the area below and downstream of the dam may be considerable. In Figs. 8–12, Plate 3, is shown a method for safely leading away such water. A dry-stone drain, having a vent of say 4 inches by 6 inches, would be formed at the downstream base of the puddle trench; this would be enclosed in a mass of sound, clean rubble, say 4 feet by 3 feet, and this, in its turn, surrounded by a 1-foot layer of clean gravel, quarry spalls, coarse sand, &c., to prevent the flow of the superincumbent earth into the interstices. Where the base of the puddle trench can be excavated by hand, the drain can be shut off from the upstream part of the trench by a natural barrier of impermeable material so as to lessen the chance of direct creep of water. Where, however, it has to be blasted, a level bed would be formed throughout, or the drain sunk below the general bed when this can be done without opening fissures upstream. This drain would be led at intervals, by side-cuts and drains, through the ridge on which the dam stands, or, should this be impossible, down into the main "rear drain" below the dam. The base of the puddle trench should be wide enough to prevent direct leakage being induced along it into the drain. In a well-constructed puddle trench the subsoil water will tend to descend along the upstream face of the puddle to the base, and will then endeavour to force itself up, thus rendering the clay more absorbent and permeable. Where, however, a means of escape is provided, as by the drain above described, the small amount of percolation will be led harmlessly away, and the puddle material kept as compact as possible.

It might be considered advisable to continue the drain vertically along the downstream face of the trench, but such a long, thin layer might suffer distortion or disturbance from the lateral pressure of the puddle and the earthen sides of the trench, and

might become discontinuous and thus of little use. In the case of a concrete trench in hard soil this would not occur, and it might, with advantage, be backed by a rubble lining to act as a drain, Fig. 12, Plate 3.

Subsoil Water escaping the Trench.—Many existing dams show that subsoil infiltration below the puddle trench occurs harmlessly. The water-level of wells for some distance below the dam is raised, and small clear springs issue at rock outcrops. The total quantity thus escaping is relatively small, and it is not worth while to incur a large outlay to endeavour to entirely prevent it. Assuming the puddle trench to be soundly made and well drained at the base, it will intercept all infiltering layers which come against it; owing to its depth, water passing below it must come from a considerable distance, and its rate of flow must therefore be small. Except along the downstream slope of the trench (where it will be intercepted by the base drain), water will have no tendency to rise below the base of the dam, owing to the great superincumbent weight on it, but will seek an easier escape along some of the natural leakage-planes of the subsoil. Its quantity will almost invariably be small, but, should it be large, it may safely be dealt with at small expense by a downstream deep drain.

Foundations.

It is usually specified that the foundation of a dam should be stripped of all surface soil for 1 foot in depth, all plants rooted out, all slushy, sandy or loose material removed from the site, and all steep slopes benched to receive the earthwork.

The best foundation for a dam is compact rock, provided it is level, or at least does not slope downstream, as it would then tend to cause a slip. To prevent this its surface should be well roughened by shallow trenches parallel to the axis of the dam. The next best foundation is compact "murum," as neither of these will move appreciably under the weight of the dam. After these come, in the order named, "mán" (a soft clay rock), brown, and black soils; but they require special precautions for drainage, as they will yield under a heavy weight when sodden. "Karal," a light, powdery, marly soil, is the worst possible foundation, as it easily becomes sodden and slushy. In short, it is necessary to secure a compact, well-drained base for an earthen dam, although it is not necessary to have the absolutely rigid foundation required for a masonry dam. The thorough drainage of the base is a matter of vital necessity. To ensure it, it is always de-

sirable to select a site where the fall of the main natural drainage lines will facilitate the passage of all subsoil water.

Benched Foundations.—It is at the junction of the dam with the ground that the maximum amount of leakage may be expected, as the top soil is weathered and is not so consolidated as the subsoil. In India the soaking of the monsoons and the great drying effect of the hot weather produce considerable movements in the top soil. When black soil dries, numerous cracks, several feet in depth, are produced, and the lines of separation probably go considerably deeper. With brown soils the cracking is much less, and with those consisting of murum it is hardly apparent. In most cases, therefore, it is desirable to take greater precautions to prevent leakage along the base of the dam. For all soils that can be excavated by hand the section given in Figs. 9, Plate 3, is recommended as one well calculated to prevent the formation of a definite line of flow, and, by interposing many obstacles on the upstream side to the passage of water, to retard infiltration. The whole bed of the dam, outside the area occupied by the puddle trench, is stripped of unreliable surface soil and is then excavated into large furrows, parallel to the axis, which have the further advantage of tilting up the dam, so that its layers tend to slip inwards, not outwards. At the bases of the upstream benches small trenches are cut and filled with clay stopping to cut off leakage. Some of these should be deeper than the others, so as to make the junction line as broken as possible and to cut off all surface flows. On the downstream side the small trenches are made into drains, filled with drystone covered with a protecting casing of fine gravel, and leading out of the dam at intervals. These will uniformly drain the base of the dam, thus preserving the subsoil compact and preventing water rising into the embankment.

Excavation in the Reservoir-Bed.—It is usually specified that no excavation should be allowed within 200 feet of the upstream and 150 feet of the downstream toe. A better plan would be to make the distances some multiples of the height of the dam, as it is obviously unnecessary to take such precautions at the low flank as at the high gorge embankment over the river-bed. Such a specification for the reservoir-bed is undoubtedly good in that it would leave it with a covering, as watertight as possible, near the dam; and it might be amplified by prohibiting the entire stripping of surface soils or the digging of murum quarries within ten times the height of the dam from its toe. Although such excavations will soon silt up, still they may at first cause subsoil filtration which will act prejudicially on the newly-formed dam.

The "Surface Drain" at the Downstream Toe, Figs. 9, Plate 3.—There does not seem to be any harm in making excavations of small depth at a short distance from the downstream side of the dam provided they are drained and the formation of swamps is prevented. The general line of thrust due to the weight of the dam must be inclined downwards and the natural surface in the rear does not act as a buttress. Its only useful property must be its weight, tending to prevent bulging upwards of the subsoils; a slight removal of the top soil will have an inappreciable effect in this direction. It is far more important to secure thorough drainage of the ground immediately downstream of the dam, and, for this purpose, it is advisable to slope off the natural surface, say for 30 feet, at 1 in 10 from the toe. This slope will prevent water lodging even should weeds and rushes grow on it. This "surface drain" should be diverted downstream at intervals so as to prevent the formation of a scour channel along its course during heavy rainfall.

The "Downstream Drain."—Just clear of this "surface drain" should be a parallel "downstream drain," Figs. 9, Plate 3. This may have a base width of 5 feet with steep side-slopes and a depth of between 10 feet and 15 feet. It should have a small drystone drain with a 4-inch by 6-inch vent at the base, and, as it may be filled with dry material excavated from the waste weir, &c., it should not be expensive to construct. It will effectually drain the ground to the downstream of the dam, and will intercept the percolation passing the puddle trench and likely to rise in the neighbourhood of the dam. It should lead to the main "rear drain" below the dam described below.

It will also have a decided effect in reducing the salt efflorescence, which damages agricultural land below some dams. This is due to the upward passage of subsoil water, charged with dissolved salts, in excess of that which the natural subsoil drainage can pass off. As this upward moisture is being continually evaporated by the sun, the salts are crystallised out on the surface. The foundation drains below the downstream part of the dam can be led at intervals into this "downstream drain."

Open and Underground Drains.—Shallow drains are of little use in draining the rear of the dam, as they do not intercept the main sources of infiltration. The water rises between them to the surface, and, where this is clayey, marshy ground is formed, and on this grow in profusion reeds and water-plants which add a further obstacle to complete drainage.

The system of underground drains, filled with dry material,

surrounded by a filtering layer and having a cover of, say 2 feet of finer material and soil, is, in India, decidedly better than one of open drains. Owing to the severity of the rainfall and the rapid growth of plants, the sides of the latter are certain to crumble in and choke the flow. Their maintenance in water-charged earth is sure to be expensive, and, if not continuously carried out, they are liable in the course of a few years to be obliterated. The underground drains, on the contrary, run clear, weeds cannot grow in them, the sides cannot tumble in, nor can silt be washed into them from the surface.

Rear Drains.—At all valley lines crossed by the dam, "rear drains," Fig. 8, Plate 3, should be run with as good a fall as possible. They should pass off the flow from the "downstream drain" and the "puddle-trench drain," *ante* p. 134, to the natural drainage lines of the country. Where they are in soil they should be of the underground type. The main rear drain in the river bed will generally be in rock, and can in such a case be in open excavation, protected from the inflow of silt, &c., by raised side banks. As it will drain the highest part of the dam, the greatest care is necessary that it should always be clear.

The bed of the puddle trench at the river crossing will probably be near the surface; but, where it is not, and the natural fall is gentle, its base drain should be connected with the rear drain by an upwardly inclined transverse drain having its mouth a little above the bed of the latter, to prevent the inflow of water from it. This transverse drain, by affording an easy exit to the puddle-trench drainage, will prevent the base of the dam from becoming sodden. This artifice of upwardly draining subsoil water has already been tried with success in agricultural practice, where a retentive soil on rising ground is underlain by an imprisoned, permeable and water-bearing stratum. It assimilates in principle to the artesian well.

Sandy River-Bed Foundations.—Where the river-crossing is in deep and compact sand, it may occasionally be more economical to leave this on the downstream side of the puddle trench, preventing its motion by a strong masonry toe-wall. The sand will thus act as a natural drain to the base of the dam. The upstream base of the dam should, of course, be cleared of sand, and, as a further precaution against direct infiltration, the puddle trench should be widened considerably. The chief danger will be the possibly unequal settlement of the two portions of the base, but this can be obviated by raising the dam slowly, and by giving it a year in which to settle after completion before the reservoir is filled.

CONSTRUCTION OF THE DAM.[1]

General Formation.—Owing to the cheapness of labour, Indian dams are probably more soundly constructed than those elsewhere. The foundation of the dam, having been levelled, is wetted by a hose from a pump, or by "bhisties" (water-carriers employing oxen with leather water-bags placed on their backs). On this is spread the earth, which is conveyed to the site in small quantities, all clods are broken up, and the layer is carefully levelled and finally rolled. On the completion of a layer, the process is similarly repeated for the next one and so on. At the base of the dam crossing the river-bed, the layers, when rolled, should not exceed 3 inches in thickness. When the dam has been raised one-third of its height the thickness may be increased to 4 inches, and for the top third to 5 or even 6 inches.

Material.—In many of the dams constructed in recent years, the chief fear entertained was that water would penetrate them, and, in consequence, they were composed entirely of black "cotton soil" with protective casings. Although this material is very fairly watertight, still, from its greasy and unstable nature, it is not suitable by itself for the formation of high dams, and most of the slips which have occurred must be due, in a great measure, to its use.

When this fear of percolation was seen to be unfounded, more importance was attached to giving greater stability to the earth-work by forming the outer portions of the cross-section of soils, natural or artificial, having a greater frictional resistance to slipping, the hearting being still made of black soil or clay. This may be described as the present general system, and it is a decided advance on the older one. It is, however, open to the objections that in practice it is sometimes difficult to arrange for the simultaneous carrying up of layers having different materials in different parts, and to the more serious one, that by it the dam is composed of three distinct portions having different rates of consolidation and different behaviour under the infiltering action of water, whereby internal stresses are set up in the mass until it attains its final settlement. With such a material as earthwork it is decidedly better to construct the dam as one homogeneous whole so that it may act as one uniform mass under all conditions.

[1] The standard specifications worked to in Bombay are given in "Specifications, Rates and Notes on Work," by Captain Marryat, R.E., 4th edition, pp. 47–50.

There is, as a rule, in India, little difficulty in getting argillaceous material, while that necessary to furnish the needful grit is generally the more expensive to obtain. There is, therefore, no economy in limiting the use of clay to the hearting. Where, however, clay is deficient, it should be chiefly used in the upstream two-thirds of the section, a smaller quantity being reserved for mixture with the grit or dry material, forming the downstream one-third, without which the latter would be wanting in cohesive resistance. With careful construction there is no difficulty in consolidating a natural or artificial gritty, but still clayey, soil to a practically watertight mass. It is, therefore, better to make the dam of one consistence throughout, and a good proportion to adopt would be two parts of pure black soil to one part of pure "murum," or other dry material; or, such proportions of the existing soils as would result in an equivalent mixture, which is really an earthen concrete. The admixture of the dry material, besides increasing the frictional resistance of the mass, effects a means of self-drainage. As the vertical height of a dam is only about one-fifth of its width, excess percolation into the dam, at least on the downstream side, would be carried off more rapidly by the base drainage than it is produced by the hearting, and the mass would always be drier and more compact than if it were made of pure clay, which, when it has once admitted water, parts with it extremely slowly.

Such a dam should have protective casings formed with, say, double the amount of grit, and having normal widths varying from about 5 feet at the base to 3 feet at the top, to prevent solution on the reservoir side, and rain-guttering and weathering on the downstream side.

This mixture would, when compacted, be free from voids, but the small amount of clay used would be likely to render the mass permeable and possessed of little cohesive stability.

The layers of earthwork are generally constructed perfectly level, but this method can be improved upon. Mr. G. H. Darwin, M.A., F.R.S., when treating of "The Horizontal Thrust of a Mass of Sand,"[1] mentions the remark of Professor Clerk Maxwell that the "historical element" would probably largely affect the limiting equilibrium of sand, meaning thereby that sand formed in different ways would exercise different thrusts although presenting the same external appearance. The experiments he has recorded go to prove that this is the case. If it is desired that a mass of earthwork should settle tightly against a retaining

[1] Minutes of Proceedings Inst. C.E., vol. lxxi. p. 350.

wall, its constituent layers should slope towards it, and, the steeper the slope the greater would be their pressure. On the other hand, if the wall is to be freed as much as possible from earth pressure, the layers should slope from it. The same thing occurs in nature. "The stability of sedimentary rocks in the side of a cutting is greater when the beds are horizontal, or dip away from the cutting, than when they dip towards it."[1]

Applying this principle to the construction of dams, it will be seen that it is advisable to construct the layers sloping inwards so as to counteract the natural tendency to slip outwards. For convenience of working, watering and consolidation, the slope from the downstream edge of the dam should be about 1 in 10. The upstream edge should be kept at about the same level, and the slope from it flattened so that its toe is level with that of the downstream side, and so that the resultant inwardly-slipping tendency of the two opposed masses of different magnitude may be approximately balanced. The central eighth of the layer may be kept level and worked off gradually to meet the outer slopes. Care must be taken when watering that no water runs down the slopes, and that it is uniformly distributed.

During the self-consolidation of the dam, the interior portions being of greater vertical height than the exterior and being subjected to greater pressure, even originally level layers must tend finally to slope towards the centre, but the action is so small that it cannot add appreciably to the frictional stability of the dam.

It has been stated[2] that the Oued Meurad dam in Algeria, 95 feet high, constructed some thirty years ago, had its earthwork layers deposited normal to the outer slope, and, as the bank was carried up, the water was admitted and allowed to rise to near the temporary crest. As soon as the bank had settled, the earthwork was continued another grade and the same process repeated.

Mixing.—A naturally clayey and gritty soil is the best, but, as such can rarely be found with the constituents in the proper proportion, it is generally necessary to make a mixture. The black soil should be first spread on the dam and should then be covered with a layer of "murum," &c. The best way of mixing them is by hand with a large hoe; but as this is very expensive, native sharp-pointed wooden ploughs and harrows may be employed. The next best method is to use a light metal plough, which inverts the earth and mixes the two layers intimately, thus preventing the formation of a pure soil, greasy plane below

[1] Rankine, "Civil Engineering," p. 318.
[2] *The Engineer*, vol. lxiii. p. 189.

each pair. With the same object in view, in America, grooved rollers are employed, but they have not been used in India, and it is questionable if they are quite so effective as the iron plough in producing a uniform mixture.

Consolidation.—The consolidation of the layers of earthwork is principally effected by iron rollers which are drawn backwards and forwards by buffaloes or oxen until no further compression can be obtained. The dam should be constructed at least 18 inches wider on each side than the designed section, so that the roller can pass over the full final width. After the dam has been raised a few feet this surplus width can be removed and used for the upper layers. With the same object in view no patching on to the dam should be allowed, and all works-roads leading up the slope should be formed outside the designed section and should be removed by the excavator when no longer required.

A light roller should be used at first over the freshly-deposited earth to smoothen it and the consolidation should be completed by a 3-ton iron roller, 4 feet wide, until a loaded cart passing over the dam makes but a faint rut-mark on it. All rollers should be provided with automatic scrapers to prevent their lifting moist earth. At the Nagpur Waterworks a 10-ton steam roller was used; the use of this heavier roller is desirable to ensure that no vacuities are left in the dam. The weight of the dam itself is, however, the best compressor, provided that the earthwork has first been rendered compact artificially, and it is therefore advisable to let the completed section have at least one season in which it can act before the reservoir is allowed to fill, and not to raise the earthwork more than 30 feet in height in one season. The artificial compression by rollers is, however, so good that the allowance made for final settlement is only $\frac{1}{36}$ or $\frac{1}{30}$ of the total height of the embankment. A great part of this occurs during the first year after the work is completed.

Dependence must not, however, be placed entirely upon the self-consolidating powers of earthwork; for, during the settlement of an originally loose mass, a much larger amount of motion will take place, and if this is not absolutely uniform (which it cannot be owing to the varying heights in the longitudinal and cross sections) internal stresses will be set up. Moreover, the loose structure will be subject to great infiltration from rain and from the reservoir, which will keep it green and will still further tend to unequal settlement.

In confined situations, such as the junctions of two lengths of dam, the ordinary roller cannot work, and these places are consolidated by gangs of men working in unison with hand-rammers.

As they cannot compress the earth as much as rollers, these places become sites of unequal settlement, and should be avoided as much as possible. In order to obviate them it would be advisable to use split rollers on a common axle, with the animals working within their paths. At the top of the dam, where the lessened width will not allow animals to work, the consolidation should be effected by lighter rollers, running, say, $\frac{1}{4}$ ton to the foot, worked by men.

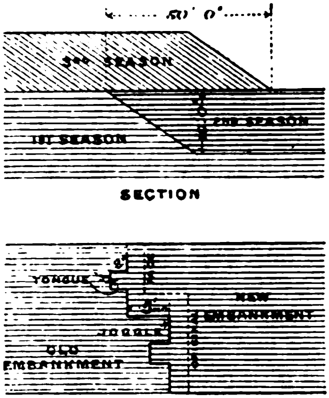
Where water is plentiful it is a good plan to water the finished slope with a hose for several days until it becomes so compacted by the washing in of fine particles that the water runs off it. The slopes thus become so hard that they will thereafter resist the guttering action of rainfall. With the same object in view, the top part of the dam should be formed of porous materials to absorb the rainfall as far as possible, and to prevent it running down the slopes in concentrated streamlets. The finished top should be covered with a layer of coarse sand $\frac{1}{2}$ inch thick. Where the top is wide, small side-banks, 1 foot high, might be constructed so as to prevent the water falling on it from guttering the slopes, or the surface may be very slightly inclined to the reservoir, so that the drainage may be harmlessly passed to the pitching. To protect the downstream slope from the weather it should be sown, at the beginning of the monsoon, with chopped "harali," a low grass of spreading habit having deep roots, which will bind the casing.

Watering.—Naturally damp earth, where available, should be used for forming the dam. Where it is not procurable it is a good plan to wet the borrow-pits overnight to produce it artificially. It is essential to secure complete union between the different layers that the finished one should be moistened before the next is put on it, so that the latter may be rolled into the former. Where moist earth is used, the wetting should be slight and done just in advance of the new layer. Where dry earth is used, more water may be given and for a longer time before laying the new layer. The test of the sufficiency of the watering is that the new layer is quickly consolidated, but yields only slightly before the roller. If there is any decided motion, it is an evidence of the formation of slush. The defective part should be at once cut out and re-made with dry material. For the reasons already stated it is imperative that only the minimum amount of water required for consolidation should be used. A dam formed of too wet material will remain green for a long time, and if the reservoir water is admitted to it while it is still wet a very undesirable amount of percolation may be set up.

Minor Precautions.—Cross-sectional junctions should be made as

shown in *Figs. 1.* All the loose surface earth of the old slope should be carefully removed and the earth joggled, as shown in plan, with inclined slip tongues to allow the new embankment to settle tightly on to the old one. Such junctions should not be more than 10 feet in height, and where a greater height is unavoidable, it should be broken up into sections, separated by horizontal breaks of at least 50 feet. They should not be carried up more than 20 feet in one season, and the work of the different seasons should break joint as shown in the sectional elevation.

Figs. 1.

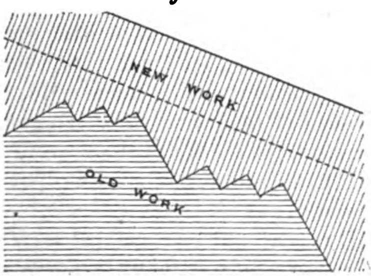


PLAN

Longitudinal junctions, or patchings, on to the slopes are most objectionable; but, where they have to be made, they should be carried out in the manner shown in *Fig. 2*, with benchings of irregular width to prevent the formation of a slipping plane, as transverse filtration need not be considered. No more than 20 feet vertically should be executed in one season.

At the gorge, or river-crossing, where the dam abuts on steeply rising ground, this latter should be cut into benches sloping into it, so that the earthwork may have a greater hold on the natural sides and less tendency to slip away from them. Each of the benches in plan should be divided into sections, breaking joint with each other, so as to prevent the formation during settlement of passages for the creep of water to take place. A smooth junction might also produce motion of the whole mass.

Fig. 2.



SECTION

To test the nature of the construction at the close of each week, small trial pits, about 2 feet square, should be dug at intervals through the week's work. The earthwork, if properly constructed, should be found only slightly moist, compact and free from distinct stratification.

During the rains, theodolite and level observations of stout pegs, driven 3 feet deep at regular intervals on fixed lines on high parts of the dam, should be maintained, and a continuous record of them kept. These observations should be continued during the year succeeding the completion of the work. Thereafter, if no great settlement or distortion has been observed, it will be sufficient to keep an annual record of the level of bench-mark stones fixed at every chain on the top centre line of the dam.

Pitching.—In all large reservoirs the upstream slope of the dam is protected from wave-wash by drystone pitching. This should be laid on a layer of hard murum, quarry spauls, &c., about 6 inches thick, covering the casing. The pitching stones are usually laid with their broadest ends downwards, and they are hammer-dressed so as to meet from 3 inches to 4 inches all round their bases, and to break bond in all directions. Owing to their irregularity, it requires careful inspection to see that this is done; but, as each stone is more or less irregularly wedge-shaped, such pitching is more stable than the older variety, in which the stones were laid to a smooth surface, with their broadest ends upwards and their points downwards. After the pitching has been inspected, by seeing that the stones are sufficiently solidly fixed to be immovable under a blow from a heavy hammer, the interstices should be filled each with a single well-fitting chip, driven well home. When possible, the pitching should not be constructed until the earthwork has had a year in which to settle.

This form of pitching is the cheapest practicable, but it has not a very sightly appearance. It is liable to have interstices in which the waves will have a blowing-up tendency, and through which water will readily gain access to the earthwork and saturate it. In these interstices plants grow near and above the full-supply level, and tend to disturb the pitching. They also afford a means of entry into the dam for vermin, who may thus be enabled to do a great deal of harm. The irregular tops of the stones offer the maximum resistance to the force of the waves, and are thus subject to their maximum displacing power. The proper inspection of the work is at all times difficult.

All this would be remedied were the pitching packed to a fairly uniform surface with fine concrete or very coarse mortar. This work could be carried out a year or two after the reservoir had filled, and while it was subsiding in level, so that it could be plentifully watered (to permit of proper setting) at a trivial cost. This form of pitching would, of course, be dearer than the ordinary

one, but it would be more durable and more easily inspected and maintained in good order.[1]

The pitching should extend from the outlet sill level to about 2 feet above the anticipated maximum wave-wash at high flood level. Its thickness should vary at different levels with the height of the waves it has to resist, which depends upon the fetch of the wind; if taken as half their height, the thickness in feet would be $0 \cdot 7 \sqrt{\text{fetch of waves in miles}}$. Practically, it would vary from 6 inches at the bottom to 18 inches at the top of the highest dams, the thickness in all cases being represented by the depth of the single stones composing the pitching.

The foundation-course of the pitching should consist of large headers sunk at least 12 inches into the natural ground, and, on soft ground, protected from being undermined by wave-wash by an apron of rubble débris, &c., from the waste-weir, &c. The top course should be formed of hammer-dressed headers with thin joints to prevent the upper earth guttering through them, and

Fig. 3. *Fig. 4.*

SECTIONS

should be laid in a continuous level line projecting at least 9 inches from the pitched face so as to act as a wave-breaker course, *Figs. 3* and *4*.

These precautions were taken for the pitching of the flank embankments of the large Dhupdál Weir, Belgaum Collectorate.

CLOSURE OF THE DAM.

This portion of the work gives the Indian engineer the greatest anxiety, as a temporary passage for an immense quantity of water has to be provided until the beginning of the last season, when the last gap has to be completed within seven months, as no con-

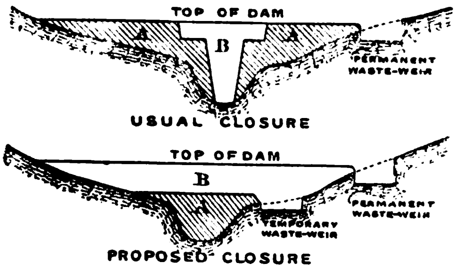
[1] The reservoir of the Stratford-on-Avon Waterworks occupies a total area of 7 acres 3 roods 4 perches; its top-water area is 4½ acres, the average depth 18¾ feet, and its storage capacity 19,200,000 gallons, All the inside slopes up to water-level are protected by 6 inches of concrete, and above that they are turfed. (*The Engineer*, vol. lx., No. 1561, of 27th November, 1885.)

siderable amount of work can be done during the monsoon, after the commencement of which the reservoir is liable to be filled within a few days. During all this time a very large body of labourers must be kept constantly at work. The fear of an outbreak of cholera, which would effectually stop all progress, is, also, ever before his eyes.

Usual Method of Closure.—The ordinary system of the closure of a dam is shown in *Figs. 5.* The flanks A A are first constructed, leaving the narrowest possible gap in the river-bed for the passage of the monsoon discharge. The central part B has then to be completed during the last season of work. The objections to this method are:

(*a*) The junction between A and B is too high. A, being made at least a year before B and having been allowed to settle in the open, has, at the time of junction, attained its practically final consolidation, whereas B is quite green. The two cannot properly unite, and there is always a risk of a leak forming at their junction.

Figs. 5.



(*b*) B, while quite green, is at once subjected to the infiltration due to a full reservoir; the water thus entering it prevents it ever attaining the density of A.

(*c*) B having to be carried up the full height in one season cannot be allowed to consolidate gradually by its own weight; it is, therefore, liable to internal stresses and distortions due to unequal settlement, which will be chiefly caused by the varying effect on the cross-section of infiltration of water from the reservoir during the first few months.

(*d*) B having to be completed in one season, the work is, to an undesirable extent, in the hands of the labourers, and strikes and higher rates are probable. Moreover, there is the fear of cholera.

New Method of Closure.—The method of closure employed by the Author at the Hubli Waterworks, Dhárwár Collectorate, is shown in *Figs. 5.* Its advantages are:—

(*a*) The junction between A and B is very much less in height than in the first case. It can, moreover, be greatly reduced, if desirable, at a small further expense by forming the top of A, near

and along the junction, as a temporary dam with reduced section on the upstream side and by removing the boundary part of this at the time of final closure. In this case there would be a step in the longitudinal section of the main dam behind the temporary one.

(*b*) A is only subject to infiltration from a low reservoir; all the upper part of the dam, with the exception of the comparatively low part closing the temporary waste-weir, can be allowed to consolidate before water touches it.

(*c*) The bulk of the dam, and, in particular, its highest sections, can be carried up slowly and evenly and allowed to self-consolidate. Only the small portion closing the temporary waste-weir will have to be done in one season.

(*d*) The work can be executed without fear of strikes, as the final closure of B involves a relatively small quantity of construction.

(*e*) The construction of A will lead to the formation of a small reservoir which will be most useful for works purposes and will save much in water charges.

(*f*) The temporary waste-weir will often provide a level site for the location of the outlet away from the gorge embankment and below the general bed of the dam.

In very high dams it may of course be necessary to extend the system by having two or more temporary waste-weirs at higher and higher levels, but the principle of execution will be the same. The final permanent waste-weir should be left open till the last to assist in discharging flood-waters at the lowest level.

Natural sites for these temporary weirs are desiderata in all dam sites, but, if not naturally existing, they can be generally formed by excavation. Sound rock is very desirable for their bed, but, where it does not exist at the proper level, erosion of the area to be eventually covered by the dam can be prevented by constructing a curtain wall at its downstream boundary, and, if necessary, water-cushion walls below this. From this point of view the best site for a dam is one having the gorge, or river section, separated by a natural hill from the flank, so that floods may be most safely diverted from it during construction.

In England the practice is to pass all floods away from the dam during construction by means of by-wash channels, but the largeness of the Indian floods and the lengths to which the flood diversions would have to be carried, put this method of procedure quite out of the question in their case. The system above advocated may be said to be the Indian equivalent of the English practice; but, in the former, the admission of only clear water into the reservoir cannot be arranged for as in the latter. Clear-

water flows would not, however, suffice for replenishment, owing to the sudden diminution of river discharges on the cessation of floods.

In a purely earthen dam the closure of the river gorge should be done by carrying up the full section right across it to the required height above the temporary waste-weir. If a reduced section is first carried up on the waterface and the rear part subsequently added, this latter will have a tendency to slip off during settlement and under the immense pressure of this the highest part of the dam. If, on the other hand, the width of the gorge is first reduced by patching on flank embankments, during settlement there will be a tendency to produce cracks and leakage planes at right angles to the section. By the system of forming the base of the gorge section with massive drystone toes (*post*, p. 156), both these methods of reducing the amount of work involved in the closure may be adopted with perfect confidence as the toes will give a large amount of support and prevent slipping, and their construction will prevent the formation of a direct leak through the dam.

In Figs. 6 and 7, Plate 3, this form of closure is shown for two proposed reservoirs:—the Máládevi (Ahmednagar Collectorate) and Tárlá (Sátárá Collectorate). Taking the general cross section, Fig. 8, it will be seen that, in the first season, of the central part, the first 20 feet (vertical) of the whole of the upstream toe and the first 6 feet of the whole downstream toe can be constructed. These will be protected from the monsoon discharge by the concrete walls at their rear, and the central wall, designed for permanently cutting off leakage, will act as a temporary water-cushion. The flank portions of these toes and the central hearting of the dam between them will be carried up with comparatively low steps well set back from each other. This central hearting will have its sides protected from the scour of floods by heavy pitching, which will have to be removed before the rest of the dam is constructed. The temporary water-cushions will serve to moderate the violence of the flood waters.

In the case of Máládevi, only the left bank need be thus treated, the natural spur being left on the right bank. In the second season the closure will be effected by completing the upstream drystone toe, whose rear concrete wall will cut off leakage, and by constructing a reduced section of the dam in its rear to the level required by the temporary waste-weir. In the third season the whole section will be completed to this level, and the rear earthwork will be held up by the completed downstream dry-

stone toe. Subsequently, the whole dam outside the temporary waste-weir will be completed, and the final closure of this latter will be carried out in one season to the full section throughout, or, where this involves a large quantity of earthwork, the top 10 feet may at first be safely raised with a reduced section on the waterface and may be completed during the following season.

For the lower Tárlá reservoir one temporary waste-weir, aided by the excavation of the permanent one being left open, will probably suffice. For Máládevi, two such temporary waste-weirs, also aided by the excavation of the permanent one, will probably be necessary and can be arranged for.

The following Table illustrates the saving in quantities effected by the use of drystone toes as compared with those necessary for ordinary gorge embankment closures in pure earth. To allow for the slower work of constructing the drystone toes, compared with ordinary earthwork, in the comparison the quantities of the former are doubled. The comparison is made with two forms of closure for the purely earthen dams: (*a*) of the benched gap only as designed for the "compound dam"; and (*b*) of the whole natural gorge in one operation. The latter is the only safe form for the closure of an earthen dam.

COMPARATIVE STATEMENT OF QUANTITIES REQUIRED FOR THE CLOSURES OF THE GORGE EMBANKMENTS.

Name of Reservoir.		"Compound Dam."			Earthen Dam. (10 feet top width, slopes 3 to 1 and 2 to 1.)			
					Benched Gap only.		Whole Gorge.	
		Earthwork.	Drystone.	Total, Col. 2 + twice Col. 3.	Earthwork.	Per Cent. of Col. 4.	Earthwork.	Per Cent. of Col. 4.
1		2	3	4	5	6	7	8
Máládevi	cub. ft.	2,554,000	1,329,000	5,212,000	11,036,000	212	13,642,000	262
	cub. yds.	95,000	49,000	193,000	409,000		505,000	
Tárlá .	cub. ft.	775,000	815,000	2,405,000	3,788,000	157	10,956,000	456
	cub. yds.	29,000	30,000	89,000	140,000		406,000	

Seeing that not more than 180 working days are available, and that the working area is comparatively small, it is not safe to count upon much more than a progress of 5 million cubic feet

(185,000 cubic yards) in one season. The closure of the compound dam is thus much more feasible than that of the ordinary earthen one.

The high flood-discharging capacity of the temporary waste-weirs should be made equal to that of the permanent one. As their flow will be uninterrupted by masonry work, their capacity for discharging the flood in its rise, foot by foot, will be greater than that of the permanent one, whose lower portion is restricted to sluice-ways between massive piers. On the other hand, the flood-absorbing power of the reservoir itself, at the lower levels at which they are placed, will be less than it is at the higher ones of the permanent waste-weir.

Design of Large Earthen Dams.

Deficiency of the Theory of Earthwork.—Properly constructed dams are amply sufficient to resist the pressure of the water they hold up. The only way it can and does act prejudicially against them is by infiltration, thus diminishing their frictional resistance and adhesion. The risk of failure lies in the liability of the earthwork itself to slip. There have been many mathematical investigations as to the behaviour of earthwork, but these have naturally been confined to laboratory experiments; and, although they are most useful in indicating the character of the forces at work, they cannot, from the nature of things, be based on actual and comprehensive data, and cannot, therefore, give the actual amounts of those forces in all the varying circumstances which occur in practice. This is borne out by the two most recent Papers on this subject presented to the Institution. Sir Benjamin Baker,[1] Past-President Inst. C.E., has given numerous examples showing that the lateral pressure of earthwork against walls is, at most, only one-half of that pointed out by theory, and he concludes that practical considerations, rather than theoretical ones, should be taken into account when designing them to resist earth pressure. Mr. G. H. Darwin,[2] M.A., F.R.S., concludes:—"The soundest view seems to be that engineers have no better practical course open to them than, neglecting the elaborate formulas which have been suggested, to work with semi-empirical rules such as those of Coulomb, and to allow a large coefficient of safety."

[1] Minutes of Proceedings Inst. C.E., vol. lxv. pp. 207, 208.
[2] *Ibid*, vol. lxxi. p. 378.

Rankine[1] has stated:—"There is a mathematical theory of the combined action of friction and adhesion in earth; but for want of experimental data its practical utility is doubtful."

General Causes affecting the Stability of Earthwork.—Earthwork gives way by the slipping or sliding of its parts on each other. The resistance to this is due, partly to the friction between the particles, and partly to their mutual adhesion or cohesion. The friction is measured by the angle of repose, and constants for it for different soils have been determined; these are coefficients of the weight of the mass. It is greatest for coarse and least for fine soils; on it depends the permanent stability of natural earthwork. The adhesion, or cohesion, may be measured by the depth to which an unsupported face of earthwork will stand; but it is an extremely varying force, depending largely upon the state in which the material is. It is increased by a moderate amount of moisture, but is diminished by excessive wetness. The cohesion of clays is considerable, and is largely increased by a small amount of moisture. A slight addition of moisture also increases the coefficient of friction, but an excess of it acts as an unguent in diminishing it. It is, therefore, evident that any given earthwork, other things being equal, will be most stable when slightly damp, and least stable when charged with water. Its stability, therefore, depends upon the ease and thoroughness with which it can be drained of superfluous and dangerous water. Professor Rankine[2] sums up the matter thus:—"The properties of earth with respect to adhesion and friction are so variable that the engineer should never trust to tables or to information obtained from books to guide him in designing earthworks, when he has it in his power to obtain the necessary data either by observation of existing earthworks in the same stratum or by experiment."

"*Historical Element*" *of Earthwork.*—There is a further cause of variation in the behaviour of soils, and that is what Professor Clerk Maxwell has called the "historical element," which term not only comprises the manner in which the mass was put together, but also includes the different causes at work which have subsequently modified it. The effect of constructing the earthwork so as to give it initially the greatest resistance to slipping outwards has already been noticed. In nearly all earthworks, the practice is to treat the material as homogeneous from top to base, and to adopt a uniform slope throughout. The lower portions in a large dam must, however, be in a very

[1] "Civil Engineering," p. 324. [2] *Ibid*, p. 317.

different condition to the upper ones, as they are much more highly compressed and are moister. Probably the enormous superincumbent weight causes some stratification of the lower parts and diminishes their cohesion, while the increased smoothness, due to the pressure, will lessen their frictional resistance. The amount of increase of frictional stress, according to the depth below the surface, depends upon the viscosity of the earth enabling it to transmit pressure, and this must vary from point to point on the cross section. The increase in moisture at the base will diminish both the frictional resistance and the cohesion. The variation of the materials, their disposition and the methods of construction introduce further elements of change, so that there are numerous entirely hidden forces at work whose magnitude and resultant action can only be determined by the experience of the works themselves.

In Nature it is seen that hills, or even large masses of soil, have not an even slope, but one that varies from steepness at the top to flatness at the base (*e.g.* Fujiyámá in Japan). Although this form is partly due to the effects of denudation, it is also partly due to the natural slopes assumed by the material of the hills. Slips of earthwork show, at first, a similar, but more pronounced, outline. It is known, moreover, that the limit of height of ordinary earthen dams is comparatively low.[1] French engineers have placed it at 60 feet, and, although there are instances of greater heights having been successfully accomplished, engineers, as a rule, view the construction of these higher dams with distrust. Low dams can be constructed with much steeper slopes than high ones. The water-faces of dams require a flatter slope than the rear ones. From these considerations it may be deduced that in an originally homogeneous dam with plane slopes the resistance to slipping decreases with the height from the top, and that the proper section is one having the slopes continually flattened towards the base. An "empirical section" on these principles is shown in dotted lines on Fig. 8, Plate 3. Taking the whole cross section into account, it will be seen from this that a very considerable flattening of the base slopes results in a comparatively small increase of the original area.

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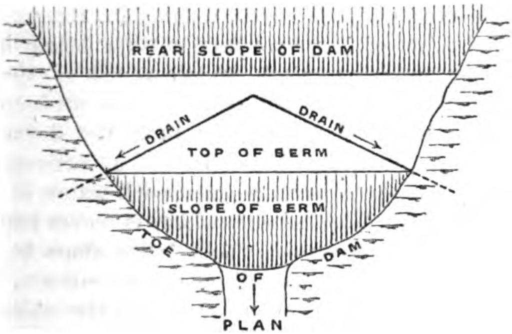
[1] Probably the highest earthen dam ever constructed was that of Estrecho de Rientes, near Lorca, Murcia, Spain, which was 150 feet high. It was commenced in 1755 and finished in 1789. The reservoir was filled for the first time in February, 1802, and the work was breached in the following April, destroying part of Lorca and drowning 600 people. The immediate cause of failure is not known. (*Vide* Mr. Gravell's Paper, *The Engineer*, vol. lxiii. p. 208.)

The Use of Berms.—In some large works, instead of flattening the slopes, the increase of base has been obtained by adding berms having the same, or nearly the same, slope as that of the upper part. Assuming the theory of the angle of rest to be correct, the earthwork in these berms is not in so stable a condition as that having the continuous flatter slopes. The total frictional resistance of the dam is a measure of its weight, and is independent of the size of the base, but its cohesive resistance is a measure of its base area. The material in a berm would, therefore, be more effectively distributed with a flatter slope. The chief advantage of a berm is to weight the surface of the dam, and thus to prevent its bulging. Another advantage of a berm is that, by its sudden increase of the section of the dam, it tends to prevent any dislocation at the top from extending to the base.

Fig. 13.



It is advisable to utilize berms for passing off the surface drainage produced by heavy rainfall, which is very considerable on a large slope area. This can be safely done by paved or watertight drains, as shown in *Fig. 13*, discharging at the downstream edge of the berm on to the natural ground. Such drains, if not watertight, would be a source of danger as they would tend to produce a definite line of supersaturation in the heart of the earthwork which might lead to the formation of a slip.

Objections to High Earthen Dams.—The "empirical section" is not recommended as a complete solution of the problem of constructing a high earthen dam. Earthwork being viscous, a small disturbance at one point is likely to extend and to cause in time a large one lower down, and it is, therefore, necessary to guard against this; the higher the dam, the greater the risk of failure. Now the highest sections of dams occur in the worst situations for

stability. The most economical line for the whole dam is generally along ridges which terminate abruptly at the river, forming a gorge. The gorge embankment is, therefore, at neighbouring points on the longitudinal section, of greatly differing height, Figs. 6 and 7, Plate 3, and this causes the formation of internal stresses during settlement. The natural steep side-slopes tend to produce slipping off of the whole mass, and the bed will generally have some fall downstream which will aid this tendency. This part of the dam will therefore be in a condition of more or less unstable equilibrium. The upstream slope will be supported by the water-pressure, or, if this is absent, by its greater mass; the two ends will be supported (or their outward motion resisted) by the natural ground or by the flank embankments, while the downstream slope will be dependent upon itself for support against the resultant stress which will be directed towards it. The tendency will, therefore, be for the dam to slip downstream, and all the slips of large earthen dams in Bombay have thus occurred, no slips of the upstream portion being known. Of course, if the upstream slope be steepened so that, with its reduced coefficients of friction and cohesion produced by water infiltration, it is relatively weaker than the downstream one, it will be the first to give. The result of experience is that the usual 3 to 1 water slope, even charged with water, is more stable than the 2 to 1 downstream one which is never exposed to the direct action of the reservoir. This latter slope is, however, in India subject to the great variations of the climate, being baked by the sun for months, and then sodden by the monsoon deluges during others. It is so wet in this latter season that its condition approximates to that of the water slope, and a less difference in the ratio of the two is necessary to give them the same slip-resisting power. It is for this reason that the "empirical section," given in Fig. 8, Plate 3, provides for a relatively greater increase, beyond the usual section, to the downstream than to the upstream slope.

Typical Sections.—The sections hitherto employed for Bombay dams are given on Fig. 14, Plate 3. The original one was defective in its narrow top width and steep top slopes, which rendered it difficult to make up any large amount of settlement. Appendix I, compiled from official sources, gives details of some of the typical earthen dams constructed according to these sections.

Top Width and Height above High-Flood Level.—The top width advocated is 10 feet throughout. The increase to this dimension will make it more in keeping with the general scale of the work. The variation in height above high-flood level of different parts of

the dam will differentiate them sufficiently without the need for altering their top widths as well; a uniform width will give the work a better appearance. With the crest wall on the upstream face the heights of the dam above high-flood level may be :—

	Feet.
(*a*) Gorge embankment and flank embankment over 50 feet high	7
(*b*) Flank embankment, 20 feet to 50 feet high	6
(*c*) Breaching section	5

The Puddle Wall.—The principal difference in construction between English and Indian dams is that the latter have no puddle wall, being constructed throughout of watertight material which obviates its use. The only plea which can be raised in favour of the puddle wall is that it is economical by limiting the amount of careful construction. Its use implies that reliance cannot be placed on the upstream half of the dam to resist water infiltration. To have so large a mass strongly saturated is very dangerous. The puddle wall is liable to become distorted and fissured during settlement, and the non-homogeneous construction of the dam involved by its use is distinctly adverse to its permanent stability. The following are examples of the dimensions of certain puddle walls:[1] (*a*) Dale Dyke dam; top width, 4 feet, batters 1 in 16, giving a base width of 16 feet where the dam is 95 feet high, which is very light. (*b*) Vehár dam for the Bombay waterworks; (in this particular not a typical Indian dam) top width 10 feet, batters 1 in 8. (*c*) The Bann reservoir and the Harelaw reservoir have both a top width of 8 feet.

Settlement.—The amount of settlement is usually taken as one-thirtieth or one-thirty-sixth of the whole height. It depends greatly upon the rate at which the dam is constructed. If it is raised slowly and uniformly, each season's work will nearly attain its full consolidation before the next is commenced, and the proper allowance for settlement will thus be at a minimum. In such a case one-fiftieth might be allowed. In addition to this the gorge section should be raised one foot higher as a precaution against its ever being topped. For the same reason the lowest and therefore the least important part of the dam should be raised one foot less than the general flank embankment so as to form a "breaching-section," which would be topped before the more important parts. The best location for this breaching-section is at a minor saddle on the longitudinal section where the founda-

[1] *The Engineer*, vol. lxiii. p. 189.

tion is hard, so that the flood resulting from a breach would be shut off from the main dam and its erosive action would be limited. Where such a saddle does not exist, a flood embankment might be constructed at right angles to the dam and retired some distance from the breaching-section.

The Compound Dam.—If the gorge embankment can have its sides confined by strong toes of some non-viscous material up to the base level of the flanks, the enclosed earthwork will be prevented from moving in any direction, and, when it is thoroughly consolidated, the upper part can be raised on it as an ordinary embankment. This constitutes the leading idea of what is now put forward as a "compound dam." The toes, if formed of trap-drystone, which has a specific gravity of 2·50 and a coefficient of friction of 0·71, compared with 1·60 × 0·50, the relative figures for moist clay, will have a frictional resistance about 2¼ times that of an equal bulk of earthwork. To give them cohesive resistance, and to prevent, on the upstream face, the inflow of water, which would lessen the effective weight, the drystone should be packed tight with clayey murum. The stone would, of course, be the roughest of rubble, and probably much of it would be obtained from the waste weir and other excavations. It would be laid with its beds normal to the slope to increase the frictional resistance. The work could be done by unskilled labour, at a cost not exceeding three times that of the earthwork; and, as the material could be stacked near beforehand, at nearly the same pace as the latter, which is a matter of great importance when the closure of the gorge is taken into consideration. To give greater frictional resistance, rubble masonry or concrete toes and core-walls are inserted along the base. The waterface of the upstream toe is covered with concrete to prevent water from entering and buoying it up, and its rear face ends in a battering concrete wall which enables the earth-pressure of the dam to be evenly distributed over it, and is useful in closing the gorge.

It may be urged that the drystone toes might be replaced by masonry retaining walls, but the proper design for these, with so large a surcharge, would be somewhat doubtful, and sufficiently massive ones would exceed the proposed toes both in cost and in time for execution. It would certainly be hazardous to construct drystone retaining walls, and the material saved by their use would not compensate for the loss of the extremely stable form of the toes, which receive the direct normal pressure of the dam and distribute it over a large cohering base.

The downstream drystone toe prevents the exposure of a large

slope area of earthwork to the effects of heavy rainfall, and thus surface drainage of the downstream slope is not necessary. Some engineers consider that earthen dams should not be constructed in extremely rainy localities, but the Máhábleshwar dam, about 30 feet high, which withstands an annual fall of 250 to 300 inches of rain (as much as 150 inches have been registered in the single month of July), and the Kás dam, 56 feet high, with an average annual rainfall of 140 inches, are instances to the contrary. Both these dams are in the Sátárá Collectorate near the crest of the western Ghauts.

To cut off leakage at the base of the dam, a concrete wall with masonry facings is provided along the centre line, and this serves as a water-cushion during the preliminary closure of the gorge. Just behind it is a continuous parallel drain formed in the usual way, and this leads out of the dam by the "rear drain" of similar construction.

The slopes of the dam are varied in accordance with what has been stated above. On the water-face and for 20 feet below the surface is a $2\frac{1}{2}$ to 1 slope, and below that, to the drystone toe, a 3 to 1 slope. On the downstream side the top, up to full supply level, is at $1\frac{1}{2}$ to 1, and thereafter the slope is at 2 to 1. This reduction of the slope at the top will effect some saving on the whole length of the dam, while it extends for so short a vertical height that any making up of the crest, required by settlement, can be easily effected.

The crest of the dam on the upstream side is formed by a wall, the extra cost of which will be met by the consequent saving of earthwork effected down the whole slope. Compared with the section having a $1\frac{1}{2}$ to 1 slope at the top, at the ordinary rates of the different classes of work, its cost will be the same for a total height of 55 feet; less for greater, and greater for less heights. Similarly, compared with the continuous 3 to 1 slope, the costs will be equal at a total height of 27 feet. It will be a more efficient and permanent form for resisting the action of the waves and for preventing infiltration, and it will protect the dam up to its crest. It should of course be constructed on a wide foundation of concrete, after the dam has attained a practically complete settlement, and this can be easily done by the general plan advocated for the gradual construction of the earthwork. The water-face is protected by stone pitching packed with concrete, or entirely of concrete, constructed after the dam has had time to settle.

The proposed general section for the flank embankment for

total heights up to 60 feet is given in Fig. 9, Plate 1. It is the same as that for the upper part of the compound dam. Where the flank exceeds 60 feet in height, it will be best to construct its base as a compound dam. This form of compound dam is of course only economically feasible where durable stone can be obtained cheaply and abundantly. This is likely to be the case at the sites of gorges, which imply the existence of hard materials, and it is for such sites that the type is best suited.

The ordinary earthen dam is the cheapest form of construction. For heights up to 60 feet it is quite safe, but its closure is difficult, and if this is not carried out in the way described under that head is likely to prove dangerous to stability. It does not require such expensive and solid foundations as are necessary for masonry dams. As all materials for its construction are obtainable close at hand, labour on it can be concentrated and easily supervised. This makes it the best class of work for famine labour, and under the present financial conditions of India, it is likely that such large constructions will be sanctioned only as famine relief works. It has the great advantage that it can be raised from time to time to meet the demands for more water, or to restore the deficiency of storage produced by the silting up of the reservoir. Its construction will generally be the quickest of all, thus enabling the work to be put in operation at the earliest date. For it the bulk of the labour required is unskilled and can thus be most easily obtained. A design for Máládevi reservoir was estimated to cost Rs.1,005,000.[1]

The compound dam described above shares all the advantages of the ordinary earthen one, and, in addition, has the further ones that it can be safely raised to a considerably greater height, and that its closure is safe and comparatively easy. It will, however, be somewhat more expensive.

The masonry dam is the most stable form. It however generally requires deep and expensive foundations, and is, therefore, not suitable to all sites. Its construction is expensive and slow. It cannot be raised beyond the originally designed height, and the only way to diminish the tendency of the reservoir to silt up is by a system of undersluices which will keep the water-level low during the early part of the monsoon. It is the best form for deep water-supply schemes where risk of failure must

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[1] The value of a rupee varies with currency fluctuations. For such works of a local character it may, however, be taken at its old value of Rs.10 = £1. At this rate the actual cost of labour is probably about one-third of its cost in England.

be avoided at all costs. A design for Máládevi reservoir was estimated to cost Rs.3,011,000.

The composite dam, having a masonry crossing of the river gorge with earthen flanks, shares the advantages and disadvantages of the two forms of structure entering into its composition. The formation of watertight junctions between the parts will involve additional but very necessary expense. A design for Máládevi reservoir was estimated to cost Rs.2,132,000.

Earthwork Slips and their Repair.

The fact that ordinary high earthen dams are liable to sudden and unforeseen slips, which may cause the breach of the reservoir and consequent damage to life and property, and will certainly involve expensive measures of repair and loss of revenue, renders them a somewhat untrustworthy form of construction. It is far better to prevent the formation of such slips at some extra capital outlay during the progress of the work, than to run any risk for the sake of a comparatively small original economy. The preceding sections have described precautionary measures, both in construction and design, and where these are adopted the chance of failure will practically disappear. A slip is the only form of damage that need be considered here. The overtopping of a dam is due to insufficient waste-weir provision, and the failure of an outlet is due to errors which are pointed out under that head. A slip may be caused in the following ways: by faulty foundations; unequal settlement producing internal stress and subsequent motion; defects in the construction or design of the dam; infiltration of water.

Faulty Foundations.—Foundations may be faulty from two causes: they may be compressible or they may be badly seated. As regards the first of these it may be stated that most dry soils can withstand the weight of a dam. Argillaceous, or partially impervious ones, are likely to give when saturated. A deep clay seat is therefore undesirable for a dam; but, where it exists, it must be rendered as compact and dry as possible on the downstream side, by a series of deep dry rubble drains parallel to the centre line, with cross outfalls as frequently as can be arranged. On both sides the slopes of the dam should be flattened so as to secure a wider base. Berms may also be added at the bases of the slopes to prevent the rise of the subsoil. If the dam is founded on a stratum which is tilted and rests on a lower one with which it is not firmly united, the extra weight on it may cause it to slide and

carry the embankment with it. Careful geological investigation is necessary to avoid this source of danger.

Unequal Settlement.—Wherever the longitudinal section of the dam varies greatly in height, and wherever the construction has not been uniform and slow, and junctions have been formed, there is a risk of the occurrence of unequal settlement, which will cause internal stresses and subsequent motion. The effect would be intensified by the action of the water which might thereby percolate from the reservoir, thus saturating the earthwork and forming a slipping plane. The place where this will most frequently occur is, of course, that where the dam was closed, should this have been done in the usual way at the river-crossing. Slips have occurred in some Bombay dams at this place, and years after their construction, showing that some slow disintegrating force, such as that described, has been at work.

Defects in Construction or Design.—The use of too permeable materials will cause a breach rather than a slip; but with ordinary care in construction, they become too compact to allow of dangerously excessive percolation. Friable materials, too loose to bind and totally wanting in cohesion, may form a slipping plane and lead to failure. Pure clays are dangerous in that their cohesive and frictional resistances become very largely reduced when charged with water, and too liberal use of water during construction is, therefore, to be strongly deprecated. Through a defective design the earthwork may be unable to support its own weight, and will slip so as to assume more suitable slopes. The profile which is only just sufficient for a dry embankment will prove too slight when it is subject to water infiltration.

Infiltration of Water.—This is the principal cause of slips, as it operates in aiding all the others to produce failure. Thorough drainage of the earthwork and of its foundations is, therefore, essential to secure stability.

The practice in dealing with slips of railway cuttings and embankments has been dealt with in the Proceedings.[1]

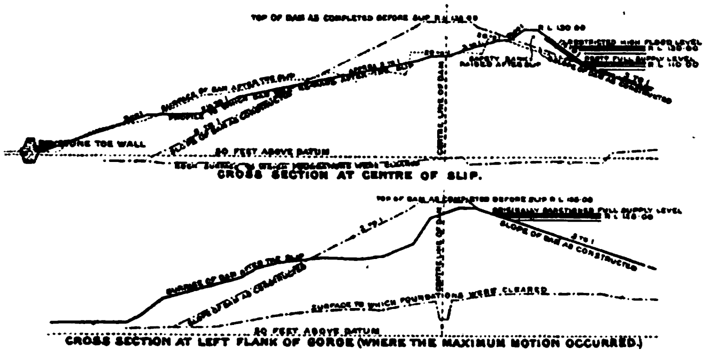
Although Indian dams are carefully constructed, still slips occur. Frequently the initial cause is obscured by the fact that several are at work together. These slips, when extensive, are of the same general form, S-shaped in vertical section, with the concave portion at the top and the convex at the bottom (when looked at from the base), and, in plan, concave to the centre-line

[1] Minutes of Proceedings Inst. C.E., vol. lxii. pp. 272, 280 and 285; vol. lxvi. pp. 256–265.

of the dam, *Figs. 15.* The layers at the base are generally tilted at an angle of about 20° to the horizon, so that the inward thrust there preserves equilibrium with the outward one from the top.

Where a slip occurs in pure black soil, its surface presents a smooth, unctuous appearance, striated by the small particles of contained grit, and parallel planes of similar surface are formed for some feet on both sides of it. It is doubtful if these will ever disappear of themselves; the result is that the fallen mass rests on a series of steeply tilted smooth, lubricated planes, and the slightest additional weight, produced either by adding more material to it or by the soakage of rain-water, will tend to cause further motion. The whole of the slipped earth has also lost all

Figs. 15.



Scale, 1 inch = 20 feet.

THE SLIP OF THE WÁGHÁD DAM.

the consolidation artificially given to it during construction. It is traversed by minor slipping planes and by fissures, all of which will admit rain-water and cause it to have a greatly reduced frictional and cohesive resistance to motion. No dependence can therefore be placed upon it, and a sound system of repair consists in entirely removing it and in replacing it by trustworthy material.

Where a slip occurs in earthwork having proper proportions of clay and grit, the latter will enable the whole to re-unite gradually, but the junction will, of course, be always a plane of weakness. This property of re-union of gritty soils is a valuable one. The slipped portion will also be fissured like one of pure clay, but the gritty particles will admit of slow self-drainage, so

that after a couple of years the earth-work will attain a fair amount of self-consolidation. The fallen mass when properly drained may, therefore, be utilized in reconstruction, care being taken to weight it very gradually, so as to let each season's work attain a practically final consolidation before the next is raised on it, and to maintain instrumental observations to detect the smallest motion. When this occurs, further additional weight should not be put on until the toe is properly buttressed.

The first thing in all repairs is to drain the slipped earthwork by drains at right angles to the axis of the dam. Of these, one should be at the centre of disturbance, and two should be along the junctions of the slip with the solid embankment; others should be inserted at convenient intermediate distances. They should be taken out, in timbered trenches, from the toe to a little beyond the innermost slipping plane, and should extend vertically throughout the mass. As soon as the excavation of each is completed, a longitudinal base drain with 4-inch breadth and 6-inch depth vent should be laid, and the trench should be filled with drystone having gravel casings at the sides and a 2-foot cover of fine stuff and earth at the top; otherwise it will rapidly choke. Not only do these drains serve their initial purpose of passing out soakage water harmlessly, and thus allowing the fallen mass to consolidate itself, but they also divide it into independent sections. It is unlikely that all these sections will tend to slip at once, and thus each at the time of initial motion is supported by the resistance of a length of the toe works considerably longer than itself. Where practicable, and when the fallen mass has been drained, the whole line of the slip should be followed up and cut out so as to get rid of the slip planes. This may be done in difficult cases by means of a timbered trench. The refilling should consist of gritty clay, with a good base drain communicating with those of the cross drains above mentioned.

The next step is to construct a strong, well-drained drystone wall parallel to the axis of the dam, and with good batters against the slip, to give the new earthwork the needful increased stability, for it will not have, bulk for bulk, the resistance of the original construction. If the fallen earthwork is to be entirely removed, this wall way be placed about the centre of the slip; if that is to be allowed to stay, it should be at its toe. To add to the stability of the repair, a strong earthen berm should be placed just below the original base, and the toe of this should be secured by a second drystone wall. All these drains and walls should, if possible, be founded on rock, but where this is not to be

found at a reasonable depth, they should be carried well into the natural subsoil and beyond the limit of disturbance. Earthwork usually fails at one point, and, as soon as it commences to move, drags the adjacent parts with it. The drystone walls, instead of transmitting the pressure directly behind them, distribute it over a certain increased area, and thus tend to prevent the initial motion. They thus act like the timbering of a trench, which, although incapable of resisting the full lateral pressure of the earthwork, provides sufficient support to prevent the first tendency to slipping.

All excavation should be carefully taken out in sections, with sufficient widths of undisturbed material between them to act as buttresses, and should be filled as quickly as possible. This, of course, results in the filling not being so well compacted as if a large area were dealt with at once, but time will remedy this. It also leads to the formation of numerous junctions, but as the sections will be constructed within a short time of each other, the earthwork on each side will eventually unite in a practically solid way.

The slip of the river-crossing of Wághád Dam, Násik Collectorate, where the designed height was 95 feet, of which 87 feet were completed, was repaired by first digging three drains at right angles to the axis of the dam. As the slip (of black soil) stood fairly well during one monsoon, it was determined to reconstruct the embankment on it, but when only a few feet had been raised, further motion was observed. As the slip was too extensive to be removed entirely, a large trench, about 250 feet long, with base width of 30 feet, side slopes 1 to 1, and maximum central height of 40 feet, was dug about half-way up it down to rock, and was refilled with drystone; a strong earthen berm was also added. The repair has answered, but the reconstruction of the dam has had to be very slowly carried out.

The less extensive slip of the 74-feet high river-crossing of Nehr Dam, Sátárá Collectorate, was repaired by excavating three main and two minor drains at right angles to the axis of the dam. In the following season the line of slip (of black soil) was excavated and the fallen earth removed and replaced by good material. In the next season a strong drystone toe-wall, with base drain, was constructed, and a berm carried up in rear. The repair is not yet completed, but it will most likely be successful.

The Waste Weir.

There are two usual kinds of waste weir: Drowned weirs or channels, and clear overfall weirs. Both of these classes are of a simple nature and their selection depends upon the nature of the ground and its levels. The channels have a level up-stream approach, and, down-stream of the weir crest, a fall of 1 in 100 to facilitate the passage of the flood with a small tail depth. The weirs are generally formed by rubble walls, protected from erosion in a few cases by aprons or water-cushions.

Where the natural level and formation permit, it is better to gain increased discharging power by converting (*a*) into (*b*). The following Table shows the discharging power per foot run of weir of the two classes:—

Discharge of Waste-Weirs per Lineal Foot.

Total depth of Flood in Feet . . .	1	2	3	4	5	6	7	8	9	10
Drowned channel (approximate) cub. feet per sec.	2·38	7·29	13·70	22·22	32·55	43·92	57·04	71·87	87·92	106·05
Clear overfall cub. feet per sec.	3·57	10·08	18·53	28·53	39·87	52·42	66·05	80·72	96·30	112·73

As regards position, waste weirs may be thus classified: (*a*) Flank weirs, at the immediate flank and in continuation of the embankment; (*b*) Saddle weirs, separated from the dam by naturally high ground.

The first kind require wing-walls to protect the end of the dam from scour, and, in some cases, a downstream lining, or curtain wall, to prevent the floods from outflanking and washing the downstream toe of the dam, or to divert the flood into a certain course. The junction of the waste weir with the dam is best effected, as shown in *Figs. 16*, by a stepped passage, which permits of easy access, and, at the same time, acts as a staunching fork. It is always desirable to excavate the tail channel with a small cross-sectional fall away from the lining wall in order to assist in diverting the floods.

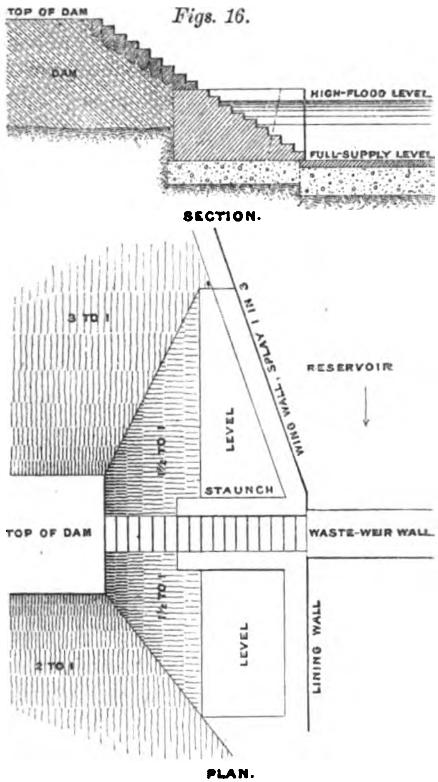
The second require no such protective works. They discharge either back into the original stream or into an adjacent one.

The most desirable outfall for all waste weirs is one into the original stream as near to the dam as possible without injuring the works or interfering with their drainage. This last is a most

important proviso as the floods, when cutting out a new channel for themselves, bring down a large amount of detritus. Where the outfall is to another stream, unless its channel is ample to pass off the added drainage, damage will be occasioned to the neighbouring lands. The bed, too, of the original stream, being deprived of scour, will silt up, become marshy, covered with bulrushes and reeds, and malarious. The subsoil water-level of the near lands will be raised and perhaps a saline efflorescence will be formed, and they will become uncultivable.

After the tail channel has reached the natural surface, no further protective works, such as cushion walls, are generally required, as the floods scour out for themselves a channel down to rock or other hard material which confines them to limits. "Retrogression of levels," or the scouring away and deepening of the tail channel back to the waste-weir itself, was much feared in the early days of reservoir construction, but this extent of denudation has not occurred as yet, and it may be arrested, when necessary, by building cross walls to serve as water-cushions.

Figs. 16.



JUNCTION OF THE WASTE-WEIR WITH THE DAM.

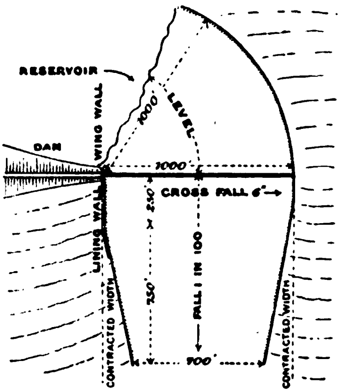
The amount of excavation of the tail channel, when it is long, may be considerably reduced by gradually diminishing its breadth, care being taken, when doing so, not to increase the tail depth of the floods at the weir crest itself, *Fig. 17.*

The depths of the maximum floods generally allowed on the waste-weirs vary from 4 feet to 6 feet, and the weirs are, therefore,

of great length. This margin of safety between full-supply level and high-flood level involves what may either be taken as a very expensive addition to the cost of the dam, or as a surrendering of a large amount of storage. In a few cases the temporary raising of the reservoir level at the end of the monsoon by a small amount, either by low earthen banks, or by teak shutters fitted into rolled beam uprights, has been attempted. The length of the weirs makes this expensive, and the design of the existing works makes it difficult to arrange for automatic or quick-acting flood discharges without which such temporary raising is attended by an undesirable amount of risk.

Mr. Craig[1] has investigated the causes leading to the "maximum flood discharge from drainage areas, with special reference to India," and has deduced the following formula for it:—

Fig. 17.



Scale, 1 inch = 1,000 feet.

PLAN OF ORDINARY WASTE-WEIR.

$$D = 440\ B\ (C\,v\,i)\ \text{hyp. log}\ \frac{8\ L^2}{B},$$

where D is the discharge in cubic feet per second; B, the mean width of the area in miles; C, the coefficient of discharge, varying with the nature of the basin; v, the velocity of the drainage in feet per second; i, the rainfall in inches; L, the length of the catchment in miles, measured from the point of discharge to the centre of the watershed base. For irregular catchments the perimeter has to be rectified by straight lines, and the whole area divided into triangles with their apices at the point of discharge. The total discharge is the sum of the discharges of the component triangles.

As this formula takes into account the varying width of catchments, their slopes and the amount of rainfall, it is more correct than Dickens' formula, which is:—

$$D = 825\ M^{\frac{3}{4}},$$

where D is the discharge per cubic foot per second, and M, the catchment area in square miles.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxx. p. 201.

Formulas are, however, not usually employed for calculating the maximum discharges of waste-weirs, partly because the coefficients would have to be worked out with insufficient data, but chiefly because the areas are comparatively so small that the maximum rainfall is fairly constant over them, and its duration is so long that time is given for the maximum flow of the tributaries to arrive at the point of discharge at nearly the same time. The exceptionally heavy rain, which is the only one to be considered in this respect, is usually very widely spread. For instance, all over the Deccán, the maximum floods of 1872 and 1882 occurred on the same days. Moreover, seeing what a disaster would be caused by the overtopping and bursting of a dam, it is advisable to always make very liberal waste-weir provision; the average cost of this is only one-eighth of that of the whole reservoir. The general practice in Bombay is to make the following allowances for average catchments:—

TABLE OF WASTE-WEIR RUNS-OFF.

Catchment Area in Square Miles . .	0–5	5–10	10–25	25–75	75–150	Over 150
Run-off in inches per hour . .	2·00	1·50	1·25	1·00	0·75	0·50

Special circumstances have, of course, to be considered; a purely ghaut catchment would be given a greater, and a purely plain one, a smaller allowance. The general intensity of heavy rainfall in the locality and flood records would also have to be taken into account.

The most noticeable feature of Indian waste-weirs is the extremely large amount of water they may have to discharge. Appendix II gives details of some heavy falls and severe floods.

The discharge of weir channels is calculated by the formulas:—

(a) $D = a\sqrt{r} \cdot c\sqrt{s}$

(b) $D = c_2 b \sqrt{2 g d_1}\left(d_2 + \frac{2}{3} d_1\right)$, or $\frac{D}{c b \sqrt{2g}} = \sqrt{d_1}\left(d_2 + \frac{2}{3} d_1\right)$,

where D is the discharge in cubic feet per second; a, the cross-sectional area of the flood in square feet; r, the hydraulic mean radius $= \frac{\text{area (in square feet)}}{\text{wetted perimeter (in feet)}}$; c, Bazin's coefficient for the tail channel; c_2, the afflux coefficient; s, the slope of the tail channel $= \frac{\text{fall}}{\text{length}}$; b, the breadth of the weir in feet; d_1, the height

of the flood afflux in feet; d_2, the depth of the tail channel discharge in feet; g, the force of gravity. D and s being given, then a $(=b \times d_2)$ is found by trial in the first formula. From the second formula d_1 is ascertained, generally by trial to avoid a cubic equation. The height to which the flood will rise in the reservoir is $d_1 + d_2$ and this has to be provided for.

A Table of discharges of a 200-foot waste-weir cut with a tail channel slope of 1 in 100 and with total flood depths varying foot by foot from 1 foot to 20 feet is given in Appendix III. As the discharges vary with the extent of the flood's wetted perimeter, the flows of weir channels of the same depth are not in exact proportion to their different widths, but, as the wetted perimeters of such floods very nearly vary with their widths, for all practical purposes, the discharges of such floods may be taken as proportionate to their widths, and especially is this the case for the small depths which are generally required. Examples bearing this out are given below:—

Length of channel	feet	1,000	1,000	50	50
Total depth of flood	„	2	10	2	10
By direct calculation .	cub. feet per sec.	7,322	106,555	362	5,180
Deduced from Appendix IV	„ „	7,285	106,050	364	5,302

The discharge of clear overfall weirs is given by the formula:—

$$D = 3 \cdot 57 b \sqrt{H^3},$$

where D is the discharge in cubic feet per second; b, the width of the crest overfall in feet; H, the total height of the afflux above the weir-crest in feet.

The existing system of waste-weirs with level crests at full-supply level is best suited for reservoirs whose replenishment is not certain. The level of these has to be kept as high as possible all through the rains, so that no storage may be lost. Such reservoirs are not situated, as regards replenishment, in the most favourable positions. The greatest objections to such weirs are that they keep the reservoirs full during that part of the year when it is most difficult to effect repairs; they prevent the reservoirs being rapidly emptied, when necessary, in the case of accidents to the dams; they impound the earliest monsoon floods, which are always the most heavily charged with silt; and by maintaining the largest reservoir areas, all floods passing through

them have the maximum time in which to deposit their silt. The silting up of reservoirs, even in a comparatively small number of years, is very noticeable; in some cases it has seriously diminished the storage capacity, and, in time, will render all reservoirs too small for their original purpose.

To remedy these defects, the Author advances what may be called a stepped waste-weir, examples of which are given in Figs. 6 and 7, Plate 1, for the proposed Máládevi and Tárlá reservoirs. The first shows the method of dealing with a saddle; while the second, that with sidelong ground, which will be the general ridge profile of most reservoirs. Such a weir may consist of four sections: (*a*) a drowned channel; (*b*) a clear overfall weir; (*c*) an undersluice section; (*d*) an automatic gate section. The last named (*d*), although very desirable, is not an essential feature, as it may be replaced by an extension of (*c*), which would have the advantage of dealing more quickly with the earlier stages of a flood. One of the largest masonry dams in the Presidency, the Bhátgarh dam, has been provided with automatic gates designed by Mr. E. Reinold,[1] and, if they prove perfectly satisfactory in practice, as is anticipated, they will form a most useful means of regulating reservoir floods at the end of the monsoon. It is, of course, not necessary that the different sections of the stepped waste weir should be continuous; they may be located to suit the contour of the ground, and may, if desirable, be situated on both sides of the river valley. Sections (*a*) and (*b*) are built with a masonry crest, preferably 3 feet below full-supply level, to allow them to be more easily closed by quick-acting teak shutters or needles. They give the weir a greater discharging power, should any excess run-off occur, than could otherwise be provided; as for any given increment in depth, the rate of increase of the discharge of a long weir with a small depth of overflow is greater than that of a short weir with a great depth of overflow, having originally the same discharging capacity. The shallow depth of storage over these sections enables the final closure to be more quickly effected; at the same time the extra length thus necessary increases the cost of the footway. Section (*c*) has its masonry crest level with that of (*a*) and (*b*), and similarly closable. The undersluices would be small and numerous so as to be cheaper and more easily worked than larger ones. The sills would be placed as low as possible. The lifting gear would be carried on arches forming part of the footway. Section (*d*) would consist of gates

[1] *The Engineer*, November 3rd, 1893, pp. 430, 431.

automatically opening on the approach of floods, and shutting on their cessation. Their tops would be level with that of the teak temporary crest. Over all sections would be carried a light footway, well out of the reach of floods, so as to permit all parts to be worked at any time. For catchments with a certain replenishment, (*c*) and (*d*) should be made large; for those with an uncertain one, they should be made smaller, and (*a*) and (*b*) increased proportionately.

Regulating Power of Reservoirs.—The property of flood absorption and regulation possessed by large reservoirs is well known, but practical effect has not yet been given to it in Indian examples. The proposed weir takes advantage of it, and in Appendix IV, Case 1, is a calculation of what may be done in this way. It will there be seen that during thirteen hours a total flood equivalent to a run off of 6·74 inches is dealt with. Of this only 1·75 inches are passed off by the weir, while the balance, 4·99 inches, is absorbed by the reservoir. When the high-flood level is reached, and assuming that the reservoir remains constant at this level, the whole weir will come into action, and its discharge will amount to a run-off of 0·487 inch per hour, giving a total run-off during the day of 11·66 inches. These runs-off are far in excess of what may be expected from the catchment. To obtain the maximum efficiency of the system, it is necessary that the reservoir level should be low before the flood comes. In the calculated example this is therefore assumed, and the waste-weir discharge at the commencement is thus only at the rate of about 0·05 inch per hour, or of 1·20 inch per day, which is, however, more than what any ordinary small flood will produce. The run-off does not reach the reservoir immediately on the occasion of rainfall, nor does it attain its maximum for some time after it has commenced, as the courses of the tributary streams are of largely varying distances from the point of discharge. There is, therefore, sufficient time to lower the reservoir by the sluices to provide for the expected flood.

Even the largest floods are of short duration, and it will be rarely, if ever, that their maximum intensity in a reservoir catchment will last for more than twelve hours, so that the stepped waste weir can pass off the largest flood and regain reservoir flood absorptive capacity before a second one arrives. For this reason the maximum rate of run-off may be safely reduced with it. In the case of Máládevi reservoir the original project provided for a run-off of 1 inch per hour; this was a very liberal allowance for so large a catchment (160 square miles), even although it is largely

a ghaut one; a run-off of 0·75 inch per hour would be more in accordance with general practice. For the "stepped weir," the maximum run-off allowed in the calculations is just under 0·50 inch per hour. The calculations show that the hourly rate of run-off disposed of gradually rises, which would be in accordance with the actual flood, and that, for the last four hours, the average hourly rate dealt with is 0·64 inch per hour.

The same property of flood absorption is shared by the ordinary level weir in proportion to the maximum depth allowed over it. Appendix IV, Case 2, shows the effect of such a weir for Máládevi reservoir. Owing to the restricted nature of the site, a comparatively short weir with a high flood on the crest is alone economically feasible, and therefore the ratio of reservoir flood absorption to the total flood is unusually high. Starting with an initial flood of practically the same intensity as that of the first case, the calculation shows that during eight hours a total flood equivalent to a run-off of 5·82 inches is dealt with; of this 2·62 inches are passed off by the weir, and 3·20 inches are absorbed by the reservoir. The discharge when high-flood level is reached will be 0·72 inch per hour, and, if the reservoir remains at this level, will give a total run-off of 17·32 inches during the day. During the last four hours of the rise of the reservoir, the average rate of run-off will be 0·91 inch per hour. It is therefore likely that the maximum flood depth will never occur, but this is owing to the large depth of flood allowed in this particular instance. In the case of ordinary depths, 5 feet or 6 feet, the flood absorptive capacity of the reservoir would be largely reduced, and the full extent of waste-weir provision would be necessary to deal with an extreme flood lasting only three or four hours.

At high-flood level (reduced level 200·00) and full-supply level (reduced level 190·00) of the 10-foot deep level waste-weir, the contents of the Máládevi reservoir are 5,212 and 3,750 million cubic feet respectively; the storage between the two is 1,462 million cubic feet or 0·28 of the whole full-supply capacity. This quantity is stored by the "stepped weir" without increasing the cost of the dam itself. In order that the storage costs of the two weirs should be the same, the expense of the "stepped weir" should equal that of the level weir plus the value of the extra storage gained by the use of the former; it will never reach anything like this high figure.

The advantages of the "stepped weir" may be thus summarized:—

(*a*) The maximum flood down the tail channel is avoided by tapping

the discharge early and allowing the reservoir to absorb the flood and give it out gradually. The action of a short, severe flood on all the works is worse than that of a long, gentle one. (*b*) It allows the reservoir's high-flood level and full-supply level to be made the same in fair weather, and thus increases its storage capacity at small expense; or, conversely, the height of the dam and its cost may be diminished for the same amount of storage. (*c*) Protective works along the upper part of the weir, where the flood action will seldom occur and will never be large, can be made much lighter, and, in cases of naturally good foundations, omitted. Hence, when it becomes necessary to raise the dam, the loss in reconstructing the weir works will be comparatively small. (*d*) It enables the tail flood to be directed along a defined and comparatively narrow channel, and thus avoids the cost of the extended protective works there which may otherwise become necessary. (*e*) It allows the reservoir to be rapidly lowered when there is any fear of danger to the dam. (*f*) During the monsoon, when any damage to the dam would be most difficult to deal with, the reservoir would be at its lowest levels, and thus the chance of damage to the works would be the smallest. (*g*) The first floods, which are most heavily silt-laden, are passed out rapidly and the storage can be effected with the river's clearest flows. (*h*) Larger catchments with more certain replenishments may be utilized without the fear of excessive silting. (*j*) It offers a greater variety of sites for the waste weir. The stepped form is generally better suited to the natural contour and requires a shorter length to accommodate it. The longitudinal section of the dam shows if the work is economically feasible; the position and levels of the waste-weir site determine if it is practicable. (*k*) As the full storage of irrigation reservoirs is not required for some years until irrigation extends, it will be feasible to keep the reservoir low and to allow the dam to consolidate by settlement with a minimum amount of infiltration; while, whenever extra storage may be required (such as during a season of scanty rainfall) it can be obtained without trouble. (*l*) The footway over the weir enables access to be obtained across it at all times. (*m*) In reservoirs with a comparatively small utilizable depth of storage an outlet might be economically formed in the deep part of the weir.

Working the Stepped Waste-Weir.—This system is best applicable to reservoirs which have a certain replenishment and which are situated on a stream having a fair flow for some time after the end of the monsoon; it is generally best to select reservoirs at sites where these favourable conditions obtain. In such cases the

sluices would all be kept open until late in the monsoon, and it would thus be only necessary to watch and regulate the few late storms which do not, as a rule, produce on fairly large catchments the excessive run-off of the earlier ones.

As a detailed example, the stepped waste-weir of Máládevi reservoir, Figs. 6, Plate 1, may be considered. During the early part of the monsoon it will store water to reduced level 177, the sill of the lower undersluices, where the storage will amount to 2,203 millions of cubic feet, or to 0·42 of the whole reservoir. During this time it will be perfectly automatic, and the total flood which can be dealt with may exceed that given in Appendix IV, Case 1, by about 4 inches, *i.e.*, while the reservoir is rising from reduced level 177 to reduced level 187. In September, the lower undersluices can be shut, giving a storage at reduced level 187, the sill of the upper ones, of 3,357 millions of cubic feet, or 0·64 of the whole reservoir. Later on, the upper undersluices can be shut, giving a storage at reduced level 196, the masonry crest of the weir, of 4,599 millions of cubic feet, or 0·88 of the whole reservoir. Up till this time it will be easy to render the weir speedily automatic by opening the undersluices. Finally, say early in October, it will be necessary to put down the teak shutters, or needles, on the crest to store the balance, 613 millions of cubic feet, or 0·12 of the full storage, and it will only then be necessary for a short time to be careful in dealing with floods. When the river's flow after the monsoon is fair in amount, this extra storage can be effected with perfect safety after its entire or partial cessation; 613 millions of cubic feet will be given by a flow of 240 cubic feet per second, lasting for one month.

It will always be advisable to maintain a sufficient establishment to attend to the weir until the reservoir has fallen a few feet below its full-supply level after the end of the monsoon, as a cheap and efficient precaution against sudden cyclonic storms. Should these occur thereafter, the reservoir will absorb nearly ½ inch run-off per foot of rise, and the automatic gates, which can easily be made to act, by filling the counterpoise chambers, will discharge more than 2 inches run-off per day. The temporary teak crest will also have been removed, leaving the masonry crest free to discharge. This will give plenty of time to open the undersluices and call the whole weir into play.

As soon as such a flood has fallen to within a foot or so above the masonry crest, it will be easy, by allowing the gates and sluices to remain open, to restore the temporary wooden crest.

Thereafter the gates and sluices can be shut, and the reservoir replenished to full-supply level, if necessary, by the tail of the flood.

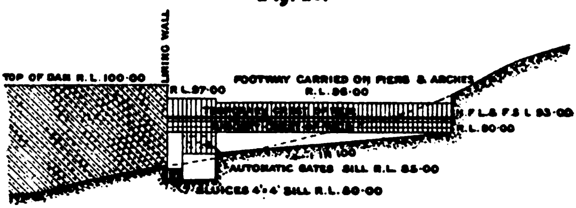
A stepped waste-weir for uncertain catchments is shown in *Fig. 18.*

The Outlet.

The various forms of reservoir outlets will be dealt with separately.

Culvert Under the Dam.—This form is usually the cheapest, and, when properly constructed, can be made perfectly safe. The objections raised to it are:—(*a*) It forms a weak point in the dam; (*b*) being under a large mass of made earth, it cannot afterwards be properly inspected or repaired; (*c*) it is apt to be disturbed by the spreading out of the dam during settlement; (*d*) it is liable to

Fig. 18.



Horizontal scale, 1 inch = 800 feet; vertical scale, 1 inch = 40 feet.

Stepped Waste-Weir for Uncertain Catchments.

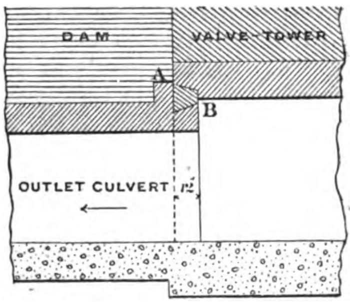
be fractured where it crosses the puddle trench; (*e*) a crack is likely to occur, owing to unequal settlement of different heights of masonry, at the junction of the culvert with the headwall or tower; (*f*) leakage is likely to occur along the outside of the culvert; (*g*) the valve-tower, if placed in the reservoir and connected with the dam by a bridge, is in an exposed position and is liable to injury by ice, or difficult of access in stormy weather; (*h*) the valve-tower, if placed in the centre of the dam, is liable to be disturbed by the settlement of the earthwork, causing a leak to form and the lifting rods to be forced out of the vertical; (*j*) where the reservoir water is admitted freely into the culvert, as in (*h*), there is danger of its leaking into the dam.

To these objections the following replies can be made:—

(*a*) This may be admitted in theory, but the objection can be met by proper precautions in design and by good workmanship. (*b*) The whole of the work being executed in the open, there should

be no difficulty in securing first-rate workmanship, and, provided durable materials, such as stone or brick, are used, there should be no need of repairs. Iron in such a position is not desirable, owing to its tendency to decay. (*c*) This is rather the fault of the embankment than of the culvert. No such spreading out of the earthwork should occur if it is carefully executed, and it has not occurred in any of the larger modern Indian dams. To meet the objection it is desirable to sink the culvert in a trench some depth below the bed of the dam, and it will then be practically independent of it. Its ends should be well buttressed by the tail and fore bays. (*d*) This is the most serious objection. The puddle-trench should never go under the culvert; the latter should have throughout its length a solid, unyielding, homogeneous foundation, not liable to be affected by the percolation of water, and this should, in all cases practicable, be of sound rock. Where rock cannot be met with, the culvert should be carried on a wide concrete foundation. (*e*) Assuming a leak to occur here, although no instance of it is found in Bombay in the numerous works of the class, it would only involve a loss of water, which would pass harmlessly through the culvert, and would not constitute a danger to the stability of the dam. At the storage reservoir of the Hubli Waterworks (Dhárwár Collectorate), the Author met the objection as shown in *Fig. 19*. The outlet culvert is overlapped 12 inches by the concentric arch carrying the valve-tower side wall. At their junction, A B, the two arch rings are bevelled as shown, and, being independent of each other, can settle independently. When final settlement has been obtained, which will be before the reservoir fills, the annular wedge space can be cemented watertight. (*f*) Direct leakage can be shut off by staunching rings. (*g*) This objection does not apply to Bombay dams where ice does not occur. Damage to the valves by floating logs, &c., can be prevented by cages. The stress of weather is never sufficient there to prevent the valves being attended to. (*h*) and (*j*) These objections appear sound, and this form of valve-tower is not employed in Bombay.

Fig. 19.



This form of culvert outlet under the dam is the form universally

adopted in Bombay for large storage reservoirs, and no failures of it have ever occurred there. At the same time the contrary opinion[1] has been expressed:—"Earthen dams rarely fail from any fault in the artificial earthwork, and seldom from any defect in the natural soil; the latter may leak, but not so as to endanger the dam; in nine-tenths of the cases the dam is breached along the line of the water outlet passages." This may be true of works carried out under imperfect supervision or of faulty design; but, as regards modern Indian experience, it is distinctly opposite to the facts in the case of large ones properly supervised and designed.

Tunnel round the Dam.—This form of outlet, being quite independent of the dam, cannot cause damage to it. The objections to it are:—(*a*) Its great expense, which is not generally necessary, seeing that the culvert form can be made quite safe; (*b*) the work, being underground, cannot be so carefully supervised as above-ground work; (*c*) the excavation of the tunnel, which should be in rock, is liable to cause fissures which will lead to loss of water; (*d*) it is difficult to construct the tunnel so as to make it have a watertight connection with the excavation. In India the scale of the natural features of the country is so large that the cost of the tunnel would, in most cases, be extremely heavy.

Siphon over the Dam.—This form can only be used where the depth to be drawn off is small; probably a depth of 15 feet is the practical limit, but to this can be added the depth below the reservoir surface at which the crest of the siphon can be laid. The culvert containing the pipes should have a wide concrete foundation to secure uniform and small settlement, and should be laid on natural ground, *i.e.*, not in the heart of the embankment. The necessity for having air-tight iron pipes in addition to the culvert adds to the expense of construction, and will, in most cases, exceed the saving, consequent on their use, of a shorter culvert and lower valve-tower. The design involves a loss of head to produce siphonage, and in many projects this would be a disadvantage. This form has been used in England and in America, but not in Bombay.

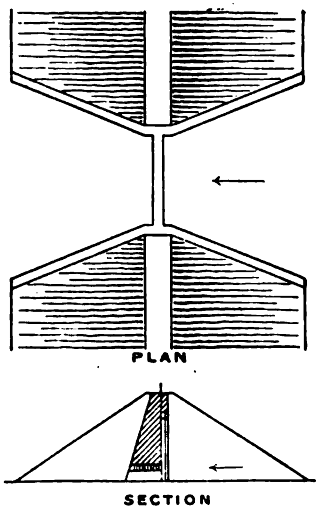
Headwall in the Centre line of Dam.—This arrangement has been employed for the large Mhaswad reservoir in the Sátárá Collectorate, *Figs. 20.* It consists of interposing in the earthen dam what is virtually a section of a masonry one and of uniting the two by four long wing walls. Great care is necessary to

[1] *The Engineer*, vol. lxiii. p. 189.

prevent the creep of water along the upstream wings and infiltration through them into the dam. The design has the great merit that the work can be most easily inspected and repaired. Rock foundations are necessary. It will be most cheaply constructed in a trench across a narrow saddle, as thereby the length of the wings can be reduced.

Headwall across an open Channel outside the Dam.—This design has been made use of in the small Medleri reservoir in the Dhárwár Collectorate. It is of very simple construction; a channel is dug around the flank of the dam, and across it is built a simple headwall in which are the regulating sluices. It is only adapted for works having a small depth of maximum draw-off. It shares all the advantages of the tunnel form, and in addition has that of being easily inspected. The disadvantage attending it is that a large area is opened out for percolation from the reservoir, and hence it is best adapted to sites where the soil is naturally watertight.

Figs. 20.



Pipe Outlets.—The dangers attending this form have been often alluded to, and it is therefore sufficient to say here that it should never be adopted for reservoirs of any magnitude or depth. There are, however, numerous small irrigation tanks of native construction where it is the only one economically practicable. For such the pipes should be laid on a hard, unyielding bed, should have staunching collars, and should be covered with the most watertight clay procurable. For these small works well-bedded earthenware pipes can be used; in some cases in Madras concrete pipes have been employed. For larger tanks with a maximum depth of from 10 feet to 15 feet, iron pipes should be laid in a trench and should be embedded in fine concrete, which will serve for the passage of the water after the iron has rusted away.

Regulating Headworks.—The different varieties of these may be classified as: Outlet towers; outlet headwalls; and dam slope gears.

Outlet towers are invariably used for water-supply storages

where the supply has to be drawn from different levels to obtain the clear supernatant water continuously as the surface falls. By their means a complete inspection of the valves and their lifting gear can always be had, and the latter is kept out of contact with the reservoir. Where double control of the supply is obtained by exterior valves, they and their lifting-gear cannot be inspected until the water-level falls.

Outlet headwalls are generally used for irrigation storages, and they have the valves placed at the sill level of the culvert. Both the valves and their lifting-gear are under water, and, according to the usual design, the former cannot be inspected until the reservoir runs dry, which, of course, it is undesirable for irrigation should occur. The remedy for this is a simple one, and consists in constructing, just upstream of the headwall, an inspection chamber which can generally be formed by throwing a cross wall between its wing walls or fore bay. The top of this should be raised to a level at which the storage capacity of the reservoir is sufficient to last from the time of inspection (which would be in May) until the monsoon replenishment arrives. At the bottom of the cross wall would be a simple sluice opening, which would be closed either by a plain shutter or by sand-bags when necessary. The same device should be adopted for the examination of the lower exterior valves of outlet towers; that of the upper ones could be effected as the reservoir surface falls. It is most desirable that all under-water sluices should be annually inspected, painted, and repaired, but with the designs now adopted this cannot be done.

In both these forms access from the dam to the valve-gear is gained by means of an approach bank jutting out with steep 1½ to 1 slopes from the dam, and a light iron bridge from it. Any settlement of the main dam would carry the subsidiary one with it, and, whenever there is a natural spur running at right angles to the main dam, the approach bank should be thrown out from it. Where this spur offers good foundations, a masonry foot-bridge can be thrown from it to the outlet headwork with advantage to permanence and appearance.

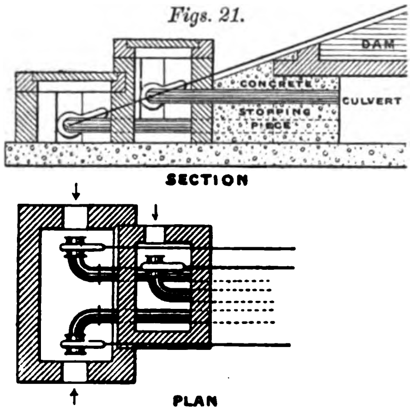
Dam slope gear.—In this form all masonry walling is avoided and the plan is a very cheap one, but it is only applicable to small reservoirs. An example, designed by the late Mr. W. J. B. Clerke, occurs in the Bhádalwádi reservoir, Poona Collectorate, *Figs. 21.* The ends of the outlet pipes are turned through a quadrant to enable plain circular valves to be used; these are situated in small masonry chambers, and the pipes are led into the culvert through

a concrete stopping-piece. The lifting rods pass through guides fixed to stones supported on the slope of the dam, and are worked by gearing at its top.

The objections to this class of gear are: (*a*) The settlement of the dam puts the guides and their stone supports out of line with the lifting rods. (*b*) The valves cannot be inspected till the reservoir is dry. (*c*) Great force is required to work the long lengths of lifting rods resting on numerous guides and actuating (in the usual plan) an elliptic-shaped gate of increased area. The guide friction could, however, be reduced by using rollers and the gate area, by the device above described.

Valves.—For water-supply purposes, where the quantity of discharge is always small, the commercial pattern of water-valve can be economically used. For irrigation outlets, much larger supplies being required, special valves are made. These consist of three parts—the fixed seating, the fixed guides between which the movable gate works, and the gates themselves. All the surfaces in moving contact should be faced with planed brass or gun-metal to diminish friction and prevent rusting, and so as to make a water-tight joint.

Figs. 21.



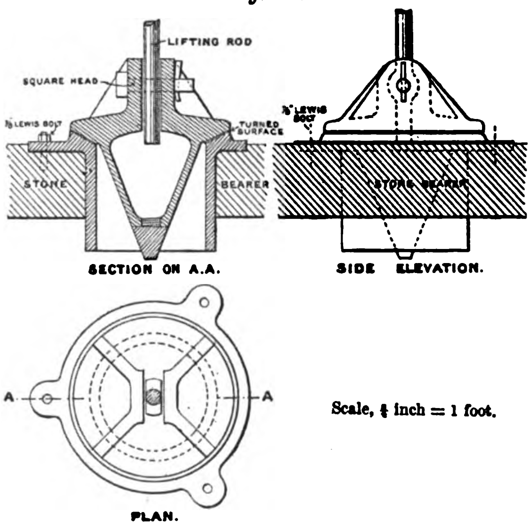
The masonry sill of the sluices should be quite below the seating, and its upper surface should bevel downwards to the reservoir to direct the outflow upwards so as to scour out any silt which might be deposited. To prevent the valve from jamming, it is best to make its bottom line part of a circle, and to slightly bevel it at the centre, which will thus guide the whole over the base of the seating.

In the small native reservoirs the outlet head consists of a small masonry chamber roofed with a slab which is pierced by an inlet hole whose discharge is regulated by a simple wooden plug fixed to a pole. A second hole is made horizontally, in the front wall, at the reservoir-bed level, and is also closed by a plug which is regulated by hand when the water-level falls below the roof of the chamber. This form has been elaborated in iron for the Gulburga

reservoir at Hyderabád, Deccán, and is illustrated in *Figs.* 22. It is simple, can be easily inspected, and enables the bottom of the reservoir to be drawn off with the maximum head. Under a great head of water it would, on account of its form, be difficult to work. By using a number of these "pole and plug" outlets, each in a chamber at a different level from the rest, it is easy to maintain a practically constant discharge by lifting the different plugs as the water-level falls.

Lifting-Gear.—The valve-rods are liable to buckle as an extreme amount of thrust comes on them when the valves jam, or do not work freely from any cause, and it is therefore advisable to make them of mild steel and of somewhat fuller dimensions than theory requires. The joints in particular are apt to give; for rods up to 2 inches in diameter, plain lap joints secured by bolts can be used, but, for larger ones, the lap ends of the rods should be confined in a strong collar with bolts passing through them and it.

Figs. 22.



POLE AND PLUG OUTLET, GULBURGA TANK.

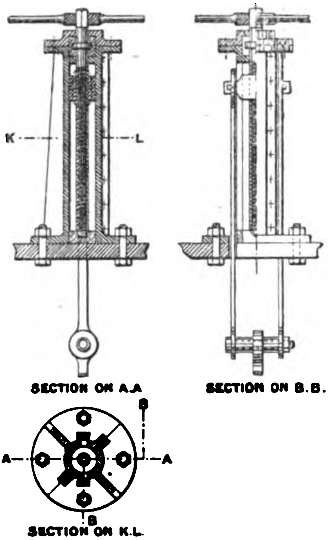
The lifting arrangements at the top consist of the screwed end of the lifting-rod actuated by a fixed capstan head. A better design, which, it is believed, is due to the late Mr. J. F. Latrobe-Bateman, has been used on some recent works. In this the lifting-screw works against a bed-step, and is separate from the lifting-rod which is fastened by a long link carried by a movable collar engaging with the screw. Any deviation of the rod from the vertical is thus not communicated to the screw, and grinding action is avoided, *Figs.* 23.

It is desirable that the travel of all lifting-rods should be visible at the capstan-pillar so that the positions of all valves in their

seats may at once be known. Where this cannot be done directly, "tell-tales" should be fixed to indicate them.

No attempts have been made in India to work the valves from the downstream end of the outlet culvert by bevel gearing and rods passing through it horizontally, but as this design would save all the expense of an outlet headwall and permit of easy inspection at all times, it might be adopted in the case of irrigation reservoirs. In this case the valve could be given either horizontal or vertical motion; the end of the valve-rod would be stepped into the valve-seating and would have a pinion engaging with rackwork fixed to the valve.

Figs. 23.



Scale, ⅛ inch = 1 foot.

OUTLET-VALVE LIFTING GEAR.

Discharge of Valves.—The discharge of the valves is usually regulated so that, with a small head of say 1 foot, the full supply may be given. Besides furnishing the supply to be utilized, the valves should, however, be sufficiently large to be of use in lowering the reservoir, when this has to be quickly done, either for their own examination or in case of accident to the dam; to steady the rise of the reservoir and save the permanent or temporary waste-weirs; to diminish silting up of the bed of the reservoir; and to aid in the closure of the dam. Taking the case of Máládevi reservoir, the outlet would have to discharge:—

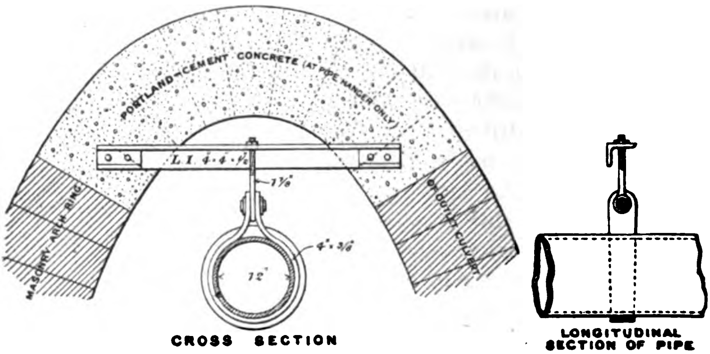
	Cubic Feet per Second.
(*a*) To lower the reservoir 1 foot in a day below reduced level 177, the sill of the lower under-sluices of the "stepped weir"	1,260
(*b*) To run off $\frac{1}{100}$ inch per day from the catchment . .	1,033
(*c*) To pass 15 inches run off from the catchment in four months of the monsoon	538

Here a discharge of say 1,000 cubic feet per second would probably be advisable. In water-supply reservoirs independent valves should be constructed with these objects in view.

To illustrate these remarks, drawings of the Hubli waterworks

outlet, designed by the Author, are given in Figs. 24 and 25, Plate 1, and *Figs. 26*. This work was modified in construction by certain changes in the valves and by the replacement of the masonry footbridge by an ordinary approach bank and iron footbridge. As stone could only be obtained at great cost, the tower was built of block-in-course facings with a hearting of very fine lime concrete (really a coarse mortar) gauged with Portland cement. The supply-valves and lifting-gear are designed inside the tower, so as to be quite protected, and double control is given to all by an extra valve placed downstream of the central stand-pipe. An inspection-chamber was built between the wings of the tower, two large unwatering valves were placed at its base, and its junction with the culvert was made as explained on p. 181.

Figs. 26.



Scale, ⅛ inch = 1 foot.

PIPE HANGER.

General Remarks on Outlet Culverts.—In Western India the form of outlet almost universally adopted for large works is the culvert under the dam, and this alone will be considered now. The position for the outlet should be very carefully selected; it should never be placed near the river gorge, as leakage from it would tend to lubricate its sides and cause the slipping of the highest part of the dam. For the same reason it is not advisable to locate it near the surface of steep sidelong ground. It should, as far as possible, be buried in a deep trench so that the friction of the filling against the sides will make it more independent of any possible movement of the dam, and so as to shorten its length and diminish its cost. It should be placed below the bed of the puddle-trench so as not to be underlain by it, but where this cannot be done, a concrete

trench should be substituted for the puddle one so as to give the culvert solid support. There will, however, in this case, be still a slight danger of unequal settlement taking place at this point. Slip-joints over the puddle-trench are not therefore required, and their use even with a puddle-trench is generally condemned in English practice.[1]

The trench excavated for the culvert should be considerably wider than the masonry and should be taken out with slightly sloping sides to give space for a good thickness of puddle so as to ensure that during settlement no leaks are formed along it. In some cases a concrete casing has been interposed between the ashlar arching and the puddle, or has been allowed to entirely supersede it. Every junction of dissimilar materials is liable to produce a leakage plane; this will be the case with concrete and any natural soil, and still more with the smooth surface of the concrete casing and the puddle round it. Puddle will fit much tighter between the rough back of the arching and the side of the excavation, and as a greater thickness of it can be used at the same cost as a thinner casing of concrete, it is better to employ it alone for surrounding the culvert.

To prevent the creep of water along the line of the culvert, staunching rings should be placed around it at intervals from the upstream side up to the line of the puddle trench. The one most upstream should be situated where it is not liable to be passed by any large amount of infiltration through the dam. The rings should be of different projections beyond the culvert so as to offer the greatest resistance to leakage along a definite straight line. They should slope in cross and longitudinal section so that the earthwork may settle tight on them. Beyond the puddle trench there should be no staunches, and the culvert should then be cased by a drystone ring surrounded by gravel to prevent the inflow of earth.

Rankine states[2] that the proper form for the line of pressure is the elliptic linear arch in which the ratio of the half span to the rise shall not be less than the square root of the ratio of the horizontal to the vertical pressure of the earth. He adds that the entire ellipse may be used as the figure of the arch, or, if necessary, the bottom may consist of a circular segmental inverted arch having a depression of one-eighth of the span. In the Wághád (Násik Collectorate) and Hubli (Dhárwár Collectorate) reservoirs, an ovoid

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[1] Minutes of Proceedings Inst. C.E., vol. lix., Wood on "Reservoir Outlets."
[2] *Ibid*, vol. lxxvi.. Burke on "The Ashti Dam," pp. 23, 24.

form was used to give a better discharging power, and the masonry invert was, for facility of construction, replaced by a flat concrete foundation. In the former the sill is 60 feet below the top of the dam and the modification has answered well. In this case a central drain should be constructed at the base to pass off any leakage that may occur. Careful attention should be paid to breaking joint in pavements and to keying the side stones below the arch ring to prevent any displacement by a large rush of water. The culvert should have a small longitudinal fall to facilitate drainage and the flow of the discharge.

Conclusion.

The Author has now dealt with all the leading features of large earthen reservoirs in Western India, and has described the usual practice and the modifications of it which appear desirable to him.

The principal feature of the works is their large scale; for, owing to climatic reasons, very large storage has to be effected and excessively large floods passed off. The remarks made have especial reference to large works, for with those of smaller size many of the precautions described are not so necessary and may be omitted. To some engineers it may appear that too much stress has been laid on these, but, as for the most part they involve more careful supervision rather than greatly increased cost of construction; and, as their adoption will greatly minimise the risk of failure, they are well worth all the attention that can be given to them. It is true that many large dams have been successfully constructed without them, but on the other hand others have given trouble which might have been avoided had the precautions been adopted. True economy and increased soundness of construction will be obtained by observing them.

For all earthwork careful selection of material and its consolidation are necessary, but the most important matter is the proper drainage of every part of the work. Up to the centre-line every precaution should be taken to prevent infiltration, while beyond this point, every facility should be given to the harmless escape of such water as has penetrated so far. Slow construction, vertically, of the earthwork, raising the highest parts of the dam first, and the avoidance of everything likely to cause infiltration or unequal settlement must be insisted upon. To suit the conditions of gorge embankments and of their closure, a new form, the "compound dam," is proposed. The closure of dams by level stages is strongly advocated. As regards waste-weirs, a new

form, "the stepped" waste-weir, is put forward, so that advantage may be taken of the flood-absorbing capabilities of the reservoir. It is best adapted to cases where the replenishment is certain, but it may be employed in others. For outlets, the type recommended as generally the most suitable is the culvert under the dam. Its size and discharging-power should be adjusted so as to make it of assistance to the waste-weir in regulating all ordinary replenishments.

The Author believes that his recommendations will not in most cases increase the cost of storage as compared with general practice, and that the works will be much safer if they are adopted.

The Paper is accompanied by four tracings, from which Plate 3 and the *Figs.* in the text have been prepared.

APPEN

COMPARATIVE STATEMENT OF CERTAIN STORAGE RESERVOIRS

1	2	3	4	5	6	7	8	9	10
			Data.			Dam.			
Consecutive Number.	Name of Reservoir.	Collectorate in which Situated.	Area of Catchment.	Average Annual Rainfall and Estimated Proportion of Run-off to Rainfall.	Fall of River above Dam.	Length of Dam.	Maximum Height of Dam.	Depth from Full-Supply Level to Sill of Outlet.	Width of Dam at Top.
			Square Miles.	([1])	Feet per Mile. ([2])	Feet.	Feet.	Feet.	Feet.
									Con-
1	Áshti .	Sholápur .	92·00	$\frac{24}{4}$	12·00	12,700	58·00	22·00	6·00
2	Ekruk .	..	159·00	$\frac{31·57}{4}$	8·50	6,940	75·66	38·25	6·00
3	Kás . .	Sátárá .	1·97	$\frac{139·67}{3}$	57·85	718	56·41	17·80	10·00
4	Maini .	..	54·00	$\frac{24·24}{4}$	29·25	3,370	57·33	31·20	5·00
5	Medleri.	Dhárwár .	11·00	$\frac{23·40}{3}$	33·50	2,250	41·00	15·00	6·00
6	Mhaswad	Sholápur .	508·00	$\frac{22·83}{10}$	12·00	7,950	79·79	24·00	8·00
7	Mukti .	Khándesh.	34·22	$\frac{20·92}{4}$	21·30	3,000	65·00	41·00	10·00
8	Nehr .	Sátárá . .	59·50	$\frac{28·37}{4}$	25·26	4,820	74·00	31·00	8·00
9	Pársul .	Násik . .	17·33	$\frac{28·00}{4}$	42·70	2,770	62·27	35·00	6 to 8
10	Wágházd	..	29·00	$\frac{54·30}{4}$	61·00	4,162	95·00	48·00	6·00
									Pr
11	Máládevi	Ahmednagar	160·00	$\frac{55·00}{4}$	5·00	4,445	114·00	63·00	10·00
12	Tárlá .	Sátárá . .	60·00	44·84	not available	3,120	94·00	60·00	10·00

[1] In col. 5 the denominator represents the fractional part the run-off bea
[2] In col. 6 the fall is taken within the limits of the full-supply contour, th
[3] The figures for these works are those given in the official projects; th
[4] With the exceptions of works Nos. 5 and 6, the outlets of all these rese

DIX I.

ITH EARTHEN DAMS IN THE DECCÁN, BOMBAY PRESIDENCY.

11	12	13	14	15	16	17	18	19	20	21
Waste Weir.						Reservoir.				
						Areas of Contours.				
Length of Waste Weir.	Height of Calculated Maximum Flood over Weir Crest.	Height of Top of Dam over Weir Crest.	Estimated Run-off per Hour.	Estimated Discharging Power of Waste Weir.	Description of Waste Weir.	At Full-Supply Level.	At Outlet Level.	Total Capacity.	Available Capacity over Outlet Sill.	Annual Depth Allowed for Evaporation and all other Losses.
Feet.	Feet.	Feet.	Ins.	Cubic Feet per Second.		Million Square Feet.	Million Square Feet.	Million Cubic Feet.	Million Cubic Feet.	Feet.
tructed.										
800	7·00	12·00	0·80	48,000	Excavated channel	123·296	23·000	1,550·000	1,348·000	4·00
750	10·00	17·00	0·42	43,763	Two channels in excavation . .	198·232	12·000	3,330·000	3,310·000	7·00
60	5·00	15·30	3·00	3,820	Masonry wall and excavated channel	3·373	0·333	..	56·567	4·00
600 300	6·00	13·00	1·11	38,668	Masonry weir wall and excavated channel. . .	16·570	1·200	195·270	188·590	5·00
700	2·00	7·00	1·00	6,453	Masonry wall and excavated channel	7·360	1·120	62·380	57·600	4·00
,000	6·00	13·00	0·73	235,545	Concrete weir wall	174·840	48·500	3,072·130	2,632·770	4·00
590	5·40 2·40	13·00	1·00	32,265	Two masonry weir walls . . .	22·177	nil	342·429	342·300	7·00
700	6·30	14·00	1·00	38,720	Masonry wall and channel . .	29·490	3·400	522·640	489·770	4·00
500	4·00	10·00	1·00	12,800	Masonry wall .	6·620	1·011	124·500	118·700	4·00
650	5·00	12·00	1·00	18,069	Excavated channel	33·900	1·657	624·670	605·550	4 00
osed.[3]										
575	9·00	16·00	1·00	103,254	Masonry wall .	153·331	18·730	5,140·370	4,921·844	4·00
600	7·00	14·00	1·00	38,000	Excavated channel	35·640	2·830	854·710	823·400	4·00

the whole rainfall: thus 4 represents ¼ the whole rainfall.
tance being measured along the bed of the river.
fer in some instances from those mentioned in the Paper.
lets consist of culverts under the dams with head-walls or towers at the upstream ends.

APPENDIX II.

I. Rainfall.

The following are instances of heavy falls of rain.

On the Lower Ganges Canal, North West Provinces, the rainfall in 1884 was:—

	Inches.
September 13th	16
October 1st	22
October 2nd	22½
October 3rd	18
October 4th	17½
Total October 1st–4th	80

Sometimes the rate was as high as 5 inches per hour. Probably this is the greatest storm on record. ("Manual of Irrigation Engineering," by H. M. Wilson, 1st edition, 1893.) It was most likely due to a cyclone.

At Jalgaon, in the Akola district, Central Provinces, on June 17th, 1888, 7·75 inches fell in six hours, from 11 A.M. to 5 P.M. (*Bombay Gazette.*)

At Saugor Island, in the Hughli, near Calcutta, 14·28 inches were registered in one day, on the 23rd (?) of August, 1888, and the wind attained an average velocity of 72 miles an hour. (*Bombay Gazette.*)

At Broach, on the West Coast, Bombay Presidency, on the 21st of June, 1893, 8 inches fell in two hours. (*Bombay Gazette.*)

At Mount Abu, in Rajputáná, in September, 1893, there was an extraordinary fall of 42 (44 ?) inches; 15 inches fell in one day. (*Bombay Gazette.*)

In Madras (town) 1 inch fell in sixteen minutes on the 11th of October, 1893. (*Bombay Gazette.*)

In Bombay (town), on the 7th of September, 1895, the rainfall at different stations was:—Colaba, 6·82 inches; Byculla, 9·50 inches; Esplanade, 7·13 inches; and Fort, 9·12 inches. (*Times of India.*) This shows how the intensity of heavy rain varies at near stations.

At Sholapur, in Bombay Presidency, on the 6th of September, 1895, 17 inches fell in twenty-four hours; at one time 10 inches being registered in seven hours. (*Times of India.*)

II. Floods.

The following are records of large floods in Khándesh, Bombay Presidency—

At Máhilla, near Dhulia, the Pánjhra river, on the 15th of September, 1872, had a flood discharge of 276,000 cubic feet per second, equal to a run-off of 0·54 inch per hour on a catchment of 788 square miles. The river rises in the western Ghauts; at its source the catchment has its maximum width of 21 miles, and is elevated and bounded by steep uncultivated hills. Uncultivated trap-hills bound the whole valley, but lower down it is itself flat and cultivated. The rainfall gauged was:—

——	Sept. 11th.	Sept. 12th.	Sept. 13th.	Sept. 14th.	Sept. 15th.	Total.
	Inches.	Inches.		Inches.	Inches.	Inches.
Pimpalner (45 miles from gauge-station)	2·13	0·20	..	9·90	0·60	12·83
Dhulia (1 mile from gauge-station)	..	0·34	..	5·69	0·36	6·39

The flood commenced to rise at 8 P.M. on the 14th, attained its maximum at 6·30 A.M. on the 15th, and returned to its original dimensions on the morning of the 16th.

At the Jámda weir, Girná river, on the 15th of September, 1872, the flood rose to 16·45 feet on the weir crest, and was calculated to amount to 373,000 cubic feet per second. The catchment area is about 2,050 square miles, extending from the Ghauts, where it is 30 miles wide, hilly and uncultivated, to the weir site where it is flat and cultivated. This gives a run-off of 0·28 inch per hour.

At the same place, on the 11th of September, 1882, there was another severe flood rising to 15·90 feet on the weir crest, but, as it outflanked the work and broke into a tributary valley, damaging the canal, and could not be gauged at the weir site, it was probably as large as the previous one. The rainfall gauged on this latter occasion, on the 9th, 10th, and 11th of September, was:—

Rain-Gauge Stations.	Ghauts.		Upper Basin.		Lower Basin.			
	Hátgad.	Allábád.	Chankápur.	Kálwan.	Nándgaon.	Málegaon.	Saigaon.	Jámda.
Miles above weir	97	82	81	71	38	34	16	−2
Inches of rainfall	22·80	56·59	12·21	14·42	9·35	8·15	5·83	3·35

The Upper Pánjhrá river has, at the site of the Dáturti weir, a catchment of 265 square miles. Its average width is 8 miles; on the north, south and west it is bounded by trap hills with steep, uncultivated slopes, the valley between being flat and cultivated. The rainfall gauged was:—

Date.	Rain-Gauge Stations.				
	Ámli.	Dáhiwad.	Pimpalner.	Sákri.	Lákhálá.
September 7th, 1882	9·71	2·03	0·12	0·29	1·35
" 8th, "		0·29	..	..	
" 9th, "		1·31	1·92	1·54	2·30
" 10th, "		4·03	4·02	2·67	
" 11th, "	5·31	4·31	4·11	3·33	2·30
" 12th, "		..	..	..	
" 13th, "		..	..	..	..
Totals	15·02	11·97	10·17	7·83	5·95

At the stations where two or more days' falls are bracketed, daily observations were not made.

The flood, as calculated from the high flood marks, amounted to 49,700 cubic feet per second, or to a run-off of 0·299 inch per hour.

During the same time, the neighbouring Burai river at Ranmálá, with a catchment of 65 square miles, which is practically uncultivated, and is elevated

with hills on the north, south and west, had a flood, similarly calculated, of 37,800 cubic feet per second, equal to a run-off of 0·90 inch per hour. There were no rain-gauge stations in this area.

Although heavy rainfall and floods are usually limited to the monsoon, they very occasionally happen during cyclones at other times of the year. A noticeable instance of this was on the 15th of January, 1871, when 15 inches of rain fell at Ratnágiri, on the coast, and 8 inches at Sátárá, to the east of, and 30 miles from, the Ghaut watershed (Bombay Presidency). A heavy flood was caused in the Krishná river.

APPENDIX III.

TABLE OF THE DISCHARGES OF A WASTE-WEIR CHANNEL HAVING A BED WIDTH OF 200 FEET AND A BED SLOPE OF 1 IN 100.

Total Depth.	Afflux Height, d_1.	Tail Depth, d_2.	Afflux Coefficient, c_1.	Channel Coefficient, c_2.	$\frac{D}{c\,w\sqrt{2g}}$.	$\sqrt{d_1}\left(d_2+\frac{2}{3}d_1\right)$.	Mean Velocity of Tail Channel per Second.	Discharge per Second, D.
Feet.	Feet.	Feet.					Feet.	Cubic Feet.
1	0 30	0·70	0·60	41·00	0 495	0·495	3·40	476
2	0·74	1·26	0·60	52·10	1·510	1·505	5·78	1,457
3	1·24	1·76	0·60	59 00	2·85	2 87	7·78	2,741
4	1·70	2·30	0·62	64·4	4·47	4·46	9·66	4,444
5	2·15	2·85	0·64	68·8	6·34	6·29	11·42	6,510
6	2·63	3·37	0·66	72·0	8·29	8·29	13·03	8,784
7	3·08	3·92	0·68	75·0	10·46	10·45	14·55	11,407
8	3·52	4·48	0·70	77·5	12·80	12·84	16·04	14,734
9	3·95	5·05	0·72	79·5	15·23	15·28	17·41	17,585
10	4·36	5·64	0·74	81·4	17·87	17·87	18·80	21,210
11	4·77	6·23	0·76	83·1	20·56	20·51	20·11	25,057
12	5·17	6·83	0·78	84·5	23·34	23·34	21·38	29,203
13	5·54	7·46	0·80	85·8	26·24	26·20	22·57	33,668
14	6·00	8·00	0·80	86·8	29·44	29·40	23·61	37,775
15	6·47	8·53	0·80	87·7	32·65	32·61	24·56	41,893
16	6·94	9·06	0·80	88·6	36·03	36·00	25·51	46,236
17	7·42	9·58	0·80	89·3	39·47	39·52	26·43	50,645
18	7·86	10·14	0·80	90·0	43·10	43·06	27·28	55,304
19	8·33	10 67	0·80	90·7	46·88	46·81	28·19	60,157
20	8·80	11·20	0·80	91·3	50·67	50·63	29·03	65,035

In the Table the afflux coefficient c_1 has been taken approximately. Rankine[1] gives Poncelot and Lebros' coefficients, which were determined from experiments with orifices only about 8 inches wide; and it is believed none on a large scale have ever been made. The values of c_1 are increased up to a total flood depth of 13 feet, to allow for the more efficient discharging power of a deep channel. No further increase is thereafter made, as large waves, and consequently more friction, will be caused. Any errors made by these assumed values will be

[1] *Civil Engineering*, 11th edition, art. 448, p. 680.

minimized in the calculations given in Appendix V, in the proportion the discharges of the waste-weir cut bear to the total flood, and this will always be small.

APPENDIX IV.

Waste-Weir Discharges and Reservoir Flood Absorptions.

Case I.—The "Stepped Waste Weir."

The "Stepped Waste Weir," proposed for Máládevi reservoir consists of the following sections:—

Section of "Stepped Waste Weir."	Total Length.	Net Length exclusive of Footway Piers.	Maximum Depth of Flood over Sill.	High-Flood Discharge.
	Feet.	Feet.	Feet.	Cubic Feet per Second.
(a) Drowned channel	625	500	4	11,110
(b) Clear overfall weir . . .	575	450	4	12,840
(c) Undersluices	200	{80 {80	23} 13}	14,208
(d) Automatic gates	200	150	8	12,108
Totals. . .	1,600	1,260	..	50,266

For (a) and (c) the effect, in reducing the discharge, of the depth of the tail channel flood is taken into account. The other discharges are not thus affected, as, with the total high-flood discharge, the water surface of the tail channel is level with the sills of the upper sluices.

The grand total discharge is equivalent to a run-off of 0·487 inch per hour from the catchment of 160 square miles.

Table of Waste-Weir Discharges and Reservoir Flood Absorptions.

Data.—The reservoir to rise one foot per hour, all sluices being fully open and the weir crest free and unobstructed. The flood to commence when the reservoir is at the level of the sills of the upper undersluices, reduced level 187, when the lower ones will be discharging 5,500 cubic feet per second, or at the rate of about $\frac{1}{20}$ inch per hour, which is equal to a fair small flood.

1	2	3	4	5	6	7	8
Number of Hours from Commencement of Flood.	At End of each Hour.		During the Hour.				
	Reduced Level of Reservoir Surface.	Height of Reservoir Surface above Bed of Waste-Weir Tail Channel.	Mean Discharge of Under-Sluices.	Mean Discharge of Waste-Weir Crest.	Increment of Reservoir Storage (or Flood Absorption).	Total Flood dealt with.	Equivalent Run-off (of col. 7) from Catchment.
		Feet.	Million Cubic Feet.	Million Cubic Feet.	Million Cubic Feet.	Million Cubic Feet.	Inches.
1	188	11	20·700	..	128·440	149·140	0·40
2	189	12	23·580	..	130·888	154·468	0·42
3	190	13	27·380	..	133·359	160·739	0·43
4	191	14	31·680	..	135·748	167·428	0·45
5	192	15	35·640	..	138·030	173·670	0·47
6	193	16	38·880	..	140 330	179·210	0·48
7	194	17	41·940	..	142·650	184·590	0·50
8	195	18	44·280	..	144·988	189·268	0·51
9	196[1]	19	46·440	..	147·358	193·798	0·52
10	197	20	48·600	5·040	149·734	203·374	0·55
11	198	21	50·220	19·620	152·130	221·970	0·60
12	199	22	51·120	41·940	154·557	247 617	0·66
13	200[2]	23	52·200	70·380	157·003	279·583	0·75
Totals			512·660	136·980	1,855·215	2,504·855	6·74
Add col. 4 total				512·660			
Total waste-weir discharge .				649·640			
Percentage quantities . .				25·94	74·06	100 00	
Add total waste-weir high flood discharge for eleven hours . .							5·35
Total run-off in twenty-four hours							12·09

Case II.—The Level Waste Weir.

The level waste weir proposed for Máládevi reservoir consists wholly of a drowned weir 700 feet long with its sill 10 feet below high flood level. Its high flood discharge will be 74,000 cubic feet per second, which is equal to a run-off of 0·72 inch per hour from the catchment of 160 square miles.

[1] Masonry crest of waste-weir.

[2] At reduced level 200 the automatic gates come into action and the total waste-weir discharge becomes 50,266 cubic feet per second, or at the rate of 0·487 inch per hour.

Table of Waste-Weir Discharge and Reservoir Flood Absorptions.

Data.—The reservoir to rise one foot per hour. The flood to commence when the reservoir is at reduced level 192, when the weir will be discharging 5,100 cubic feet per second, or at the rate of about $\frac{1}{20}$ inch per hour, which is equal to a fair small flood.

1	2	3	4	5	6	7
	At End of each Hour.		During the Hour.			
Number of Hours from Commencement of Flood.	Reduced Level of Reservoir Surface.	Height of Reservoir Surface above Waste-Weir Crest.	Mean Discharge of Waste Weir.	Increment of Reservoir Storage (or Flood Absorption).	Total Flood dealt with.	Equivalent Run-off (of col. 6) from Catchment.
		Feet.	Million Cubic Feet.	Million Cubic Feet.	Million Cubic Feet.	Inches.
1	193	3	26·460	140·330	166·790	0·45
2	194	4	45·360	142·650	188·010	0·51
3	195	5	69·120	144·988	214·108	0·58
4	196	6	96·300	147·358	243·658	0·65
5	197	7	127·080	149·734	276·814	0·74
6	198	8	162·360	152·130	314·490	0·85
7	199	9	201·240	154·557	355·797	0·96
8	200[1]	10	244·260	157·003	401·263	1·08
Totals			972·180	1,188·750	2,160·930	5·82
Percentage quantities			44·99	55·01	100·00	
Add total waste-weir high flood discharge for sixteen hours .						11·50
Total run-off in twenty-four hours						17·32

[1] High flood level.

Discussion.

Sir John Wolfe Barry. Sir JOHN WOLFE BARRY, K.C.B., President, was sure the members must regret that the Author was not present to further elucidate this admirable Paper. They could not but highly appreciate gentlemen who came, or sent such communications, to the Institution, and gave the result of the experience which they had gained in other countries. They all recognized that sound engineering consisted of a thorough knowledge of general principles and their adaptation to local requirements; and it was in that way that the experience gained in other countries became so valuable where local matters, local soils, and local conditions modified the English practice. The Proceedings of the Institution were greatly enriched by such Papers. They could not but recognize that the Author must have had a very large amount of valuable experience in India to have put together so carefully and so lucidly not only the principles, but also the practice, which had governed the enterprises with which he had been connected. He felt quite certain that the Paper would be of great interest and value to engineers, not only in this country, but in all the other countries which English engineers frequented, and where they had to do their work under varying conditions of rainfall, soil, climate and geology. He should only be saying what was in the minds of every one when he asked them to pass a hearty vote of thanks to the Author for his Paper, for the great care which he had bestowed in its preparation, and for the careful and lucid manner in which he had brought it before the Institution.

Colonel Pennycuick. Colonel PENNYCUICK, R.E., thought the first point that would attract the attention of engineers accustomed to the great irrigation systems of the South of India, was the manner in which those particular districts of the Bombay Presidency were handicapped with regard to irrigation by their geographical position. The Deccán districts to which the Paper chiefly referred were situated near the head waters of the Godavari and Kistna. The catchment basins with which they dealt were small; they were broken up in well-defined valleys separated by distinct spurs, and the consequence was that each reservoir must depend entirely upon its own catchment basin for supply. Those catchment basins were very small, and the rainfall on them had to be used; so that the two best forms of irrigation employed in Madras were inapplicable.

The first of those, which was seen in the great delta works and in the great canals of Northern India, was that in which the supply was derived from a perennial river, or if not perennial, sufficiently so to give a constant flow during the time irrigation was required, and no storage was necessary. The next best form was the typical Madras reservoir, in which a reservoir closing a comparatively small catchment-basin received its supply from a nearly perennial river or from a river which remained in flood for some time, which was diverted into it by means of a dam; not only, therefore, were the reservoirs much easier to construct, but the enormous surplusage which the reservoirs in Bombay had to provide was not necessary. He was impressed by a Table, Appendix IV, which showed the enormous provision, and the consequent expense which had to be incurred in providing for surplus water; that difficulty was to a great extent avoided in Madras. The differences in practice in detail were also interesting; in the first place as to the section of the dam. In those districts the English practice, of giving a very gentle slope to the water side of the dam, was followed; but it had long ago been entirely abandoned in Madras, where the water slope was made not more than $1\frac{1}{2}$ to 1, and the stone pitching really supported the dam. He thought, in the Author's compound section, Fig. 9, Plate 3, that if half the amount of stone was put in the form of a revetment it would certainly make a more economical section and, he thought, a safer one. He could not speak too highly in praise of the Author's remarks in that portion of the Paper dealing with slips; it was in exact accordance with the conclusions arrived at after much longer experience in Madras, and the whole method of dealing with slips and tank embankments might be summed up in one word, "drainage"; the water should be got out as soon as it got in. Perhaps no point connected with hydraulic engineering was so difficult and so troublesome as settling the amount to be provided for surplus discharges. The Author gave a formula, apparently with approval, of deducing the maximum flood-discharge from drainage-areas. He could not help thinking that complicated formulas of that kind were of little use, because an element of personal judgment was still involved. That formula included a hyperbolic logarithm, and governing it all there was a coefficient of discharge varying with the nature of the basin, and that really was the crux of the matter. In the north of India a formula was used based simply upon the drainage area, which, he thought, was raised to three-quarter power, with a coefficient in which the personal element came in as usual. In Madras the same formula was Colonel Pennycuick.

Colonel Pennycuick.

used, except that the drainage area was raised to the two-thirds power. On behalf of the younger generation of engineers he would venture to make a slight protest against the growing tendency of saddling them with exceedingly complicated formulas, mostly made in Germany, which, after all, were not nearly so useful as the much simpler equations used by their predecessors. It was stated by the Author that puddle walls were seldom used in India, and that was the case; but in some cases they were necessary. The usual practice in England was to place them in the middle of the dam. If they were necessary at all he thought the nearer they were placed to the front slope the better. The objection to this course was that they could not be symmetrical, and that they were liable to slip and to crack. But he had proved in his own experience that they could be placed quite close to the front wall. The only large work with which he had had to deal during the last 20 years in which a puddle wall was necessary was the restoration of the Redhill dam in Madras, which had been injured by a cyclone in 1884. There he had the courage of his opinion, and placed the puddle wall immediately behind the revetment, and it was there to the present day, and had given no trouble.

Sir Alexander Binnie.

Sir ALEXANDER R. BINNIE joined with the President and the last speaker in adding a word of praise to the Author for his most valuable Paper. As the President had pointed out the general rules of the profession must have individual circumstances governing their application; and he had seldom seen a Paper on the subject with which the Author dealt which so fully impressed the importance of drawing very clear definitions before any general rules were laid down for the construction of reservoir embankments. Attention had been drawn by the Author to some of the difficulties which he met with in the construction of reservoir embankments in Western India. The Paper appeared to be leading up to a certain proposed reservoir, No. 11, Ahmednagar, with a height of embankment of 114 feet. He thought that really was the object the Author had in view in bringing his opinions before the Institution, that in all probability he might receive some hints or expressions of opinion before attempting a work of such dimensions, which were seldom constructed in India or in any other country. The peculiarities with which the Author had to deal—and engineers who had had to work in Western India were fully conscious of the nature of those peculiarities and difficulties—were largely summed up in the words which so frequently occurred in the Paper—"Black cotton soil." Any engineer who

had had to work with black cotton soil soon learned that it was one of the most treacherous materials with which either a railway road or reservoir embankment could be formed. There seemed to be a slight confusion in the Paper between clay and black cotton soil. No doubt in India black cotton soil was largely used to perform those duties which were generally imposed upon clay puddle. The heartings of the reservoirs in the Bombay Presidency were apparently entirely formed of black cotton soil. Were he describing black cotton soil, he should say that it varied between slippery mud on the one hand and a dry consolidated dust on the other, full of large fissures such as those that the Author had described. If it could always be kept at a certain moisture, governing the exact amount of that moisture, it would stand up like clay; but if a very small addition of water was made to it it flowed in a very unpleasant manner. That was the first difficulty with which he had to deal—the nature of the material of which the embankment had to be formed. The second difficulty was the climate under which the work had to be carried on. He knew what those conditions were when working against time, the rains inevitably occurring somewhere about the 15th June. The work had to be carried on, and it must be completed by that date, otherwise, if the proper precautions were not taken, the whole of the season's work would probably be removed. In dealing with those two difficulties, the Author's methods would be seen from the typical section. He used the black cotton soil as puddle would be used, only he used it in a large mass. To prevent its coming outwards he had selected material; but he used the words "selected material" in a different sense to that in which English engineers would use them. They backed up their puddle-walls with selected material; but they meant in their specifications—and it was so generally expressed—the most retentive material; whereas the selected material which the Author used was the heavier, and drier, and more porous material; the heavier material being to weigh down the 1 to 1 slope of black cotton soil on which he depended for the watertightness of the embankment. Much of the Paper dealt with the precautions which should be observed in draining off the water that would percolate through the embankment or through its foundations, and there was little doubt that that was largely due to the fact that in India the puddle-trenches were not carried to so great a depth as they were in England. In constructing a reservoir in England engineers aimed at making the reservoir perfectly watertight, first with regard to the ground on which it stood, by a puddle-trench sunk down and carried Sir Alexander Binnie.

Sir Alexander Binnie.

horizontally by each end of the dam into retentive material; and for the watertightness of the embankment a puddle-wall was depended upon. When in India—as he had described a good many years ago to the Institution [1]—he did not adopt, nor should he be inclined, were he able to obtain clay, to adopt, a large mass of this very treacherous material—black cotton soil—in the section of the embankment. He went a considerable distance and obtained clay, and made a clay-puddle wall as in English practice; and he felt certain that he adopted in that particular case—and twenty years' experience had proved that it had stood since—the best that was then at his command. Placing the puddle not in the wall but on the upstream side and below the revetment of the slope—as mentioned by Colonel Pennycuick—was a matter which he should not like to adopt in India. The exposure of the slope to the heat of the sun during the dry season, and the vermin (rats and snakes), boring holes so near the surface, he was afraid would tend to bore holes through that, to say nothing of what was known to have occurred in England in several cases of the whole slipping down into the reservoir when saturated with moisture. The length of the puddle-trench must also be greater than if carried in a straight line. Two methods of dealing with the floods which came down during construction were pointed out by the Author in *Figs. 5*; one was to raise the bank in steps, as was shown at A and B, forming temporary waste-weirs at the end of the dam. That he adopted at Nagpur. In Figs. 6, 7, Plate 3, there were two methods, one to close the centre and raise the weirs one by one, or to leave a gap as shown in the upper diagram, *Figs. 5*, at B, which had finally to be closed when the whole embankment had its two flanks completed. The circumstances of the case must really govern which of those two methods to adopt. The second one, the upper one in No. 5, was certainly the least reliable, because of the difficulty that always existed in forming a proper junction between the two flanks of the dam, already constructed, probably a year or so old, and the sudden closing of a narrow and a comparatively high section of the dam in one season. He had had to do it; but it required great care. He had done it successfully in an embankment 84 feet high, but it was a task not to be lightly undertaken, except under the pressure of inevitable circumstances. The outside pitching of reservoirs in India was advisable in certain cases. There was an instance in one of the early Papers of the Institution describing reservoir construction

[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 1.

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in India, a Paper[1] by Mr. Conybeare on the Vehar Reservoir at the Bombay Waterworks, that was entirely pitched with beautiful square masonry which stood to the present day. But it was not an absolute necessity of the case in India, as was shown by most of the examples of reservoir and tank embankments, which were really slopes covered with grass in the usual manner. In very heavy rain districts, such as those spoken of in the Paper, where about 200 inches fell in the monsoon months, great care must be taken to prevent runs of water from the top of the bank coming down and forming channels in the rear slope; but that had been overcome and could be overcome with proper precautions. There was one feature on the sections to which he wished to draw attention, because it had given him, both in India and in England, a great deal of trouble, namely, terminating the slope by a wall at the top, or sometimes by some older engineers in England by a very elegant curve of the kind shown in Figs. 9. What he had always found to occur in such cases was, whether it were a vertical wall or a curve, that if there was a long reach of the reservoir and heavy waves got up, they washed up the slope, struck the portion A of the curve, and soon loosened the pitching, and the whole fell in, a great gap being formed in the top of the bank. If it was in an out-of-the-way place, where the inspectors could not look after it, it was apt to become a source of danger, as the whole bank might be breached if the top width was not sufficiently great. It was far better to carry the slope, whatever it might be, as in Fig. 14, Plate 3, straight down from the top of the embankment rather than adopt such a section as in Fig. 8, for instance, or as in Fig. 9. Where works were constructed as they were in India, and sometimes in very out-of-the-way places, and had to be left during the monsoon months to look after themselves, it was a detail which sometimes gave a great deal of trouble. As to the precautions which should be used in building an embankment of 114 feet in height, the opinions of French engineers on the subject were known. They thought that embankments of earth exceeding 60 feet in height were not to be relied upon. He thought that the experience of the late Mr. Hawksley and Mr. Bateman showed that in England, at all events, reservoirs could be constructed and embankments raised that had stood for many years of a greater height. He had had to construct one 125 feet in height, and it stood to-day as good as it did 14 or 15 years ago, when it was

[1] Minutes of Proceedings Inst. C.E., vol. xvii. p. 555.

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constructed. But while that was the case extra precautions had to be taken when so difficult a work as an embankment of that height, constructed for the purpose of retaining water, was attempted. It gave him much anxiety in drawing the specifications and designing that work; and he would endeavour to point out some of those precautions which the Author evidently anticipated would have to be taken. He thought the Author had wisely adopted the running out to 5 to 1. When it was contemplated what the slopes of natural hills of clay were, they did not come down at uniform slopes from the top. Or, what was perhaps better, the slope which might be seen in some of the deep cuttings on the main lines of railway on the outskirts of London, was steep at the top, flatter in between, and then steep at the toe. That was the angle of repose apparently that a great many clays naturally assumed when left to themselves. So that, in looking at the slopes of a very high embankment, he could not but think that the inclination should decrease as the toe was approached, both on the water and on the down-stream side. But even under those circumstances, so treacherous was earthwork that additional support was required, and in the case to which he was alluding he used in a modified form what the Author proposed to do. He placed on the inside and the outside of the embankment a dry-stone toe formed of all the excavation that came from the trench, which was carried down to a depth of about 90 feet at the flanks of the dam, and to about 30 feet where it crossed the stream, and which trench 6 feet wide was filled with 6 to 1 Portland cement concrete. He had plenty of the material, and it being in a mill-stone district, broken stone could be obtained from any quarry in the neighbourhood in ample abundance. The two toes of the slope were protected in that way. With regard to drainage, he carried up through this dry toe, almost to the point where the puddle-walls stood, a large dry-rubble culvert along the old stream course, so that the outer base of the bank was drained as perfectly as it was possible to be; and from that main culvert which ran up the old stream course he carried up drains into and under the side of the rear slope of the embankment. With those precautions, and the precautions which every engineer would take in consolidating the earthwork, and first of all forming proper puddle and then seeing it properly deposited and worked in, he thought there was no difficulty in constructing embankments of 100 feet to 120 feet in height. Each particular case must be governed by its peculiar circumstances; it was not everywhere that such an embankment could be constructed, but the circumstances

being suitable he saw no reason why such an embankment as was proposed by the Author should not be carried out. Sir Alexander Binnie.

Mr. G. H. Hill would have preferred to have carried up a central puddle-wall in the embankment, a cross section of which was shown in Fig. 9, Plate 3, and to rely upon that central puddle-wall for the watertightness of the reservoir. In England engineers carried the trenches down to a great depth in order to prevent the percolation of water through the embankment and through the ground forming the base of the embankment. The trenches varied considerably in depth; in one with which he had been connected, and of which Mr. Gale of Glasgow was the engineer, the depth of the foundation at the deepest part was 212 feet below the surface. He had had to deal with many embankments where the depth of the trenches had varied between 120 feet and 150 feet below the surface. He did not follow the Author's meaning, as to leakages having to be dealt with, because the endeavour in England was to stop all leakage. Foundations might occasionally occur in rock which might be slightly fissured; a foundation of concrete was generally inserted about 5 feet deep with a depression in the centre so that the main puddle-wall would be brought down and tied into it without having a horizontal line through the trench. He had done that in a great many cases and had found it effectual in all circumstances where it had been used. In putting in a central puddle-wall great care was taken as a rule that on each side it should receive the support of the best material available in the excavations, and then, in order to avoid slips in the slopes of the embankments, the whole of the toe of the embankment was made of the stony or gravelly material, so that it acted as a sort of retaining wall for the central part of the dam. As to the base of the embankment on the outside of the puddle-wall, all soft material was taken away from it, and it was thoroughly drained. In cases where there was fissured rock and the entire escape of water could not be prevented, he generally brought up, on the outside of the trench in a groove cut into the side of the trench, a vertical pipe, so that any water passing underneath the trench could get away without causing mischief to the work. He brought up the vertical pipe on the side of the trench and then carried a pipe to the outside of the embankment under the base of the embankment and delivered the water, which went as part of the compensation water. He had many such cases, and in some those pipes had become completely silted up in the course of years. In one case in Yorkshire, in which the depth in the Mr. Hill.

Mr. Hill. reservoir was 80 feet, there was a leakage round the embankment, not through the work but simply through the fine joints in the rock, of about 440,000 gallons a day. That water was taken down in a pipe as compensation water, and not a drop was lost. But in the course of 2 years there was no leakage, the rock was silted up and then the pipes were taken out. The great point in that kind of work was to see that the artificial work was right. The water passing round the ends of the trenches, if it passed through crevices in the rock, would do no mischief provided it came out clear at the outside of the slope and if thorough drainage at the base of the embankment was provided for. He thought, in the case of the pitching on the inside slope, it would be better to carry the slope to the top of the embankment rather than curve it up, as Sir Alexander Binnie had suggested, or even erecting a wall there. With regard to the wall on the embankment, he should not like to construct an embankment in that manner. He had a case in the Halifax Waterworks where the reservoir was about 1 mile long, and in a gale of wind—it was in a narrow valley—the water was carried over the embankment and down to the outside slope. There was a macadamised road on the top of the embankment and the water knocked the fence down and made a large hole. That was by a storm in England; he did not know whether they were worse in India. He then determined that in all cases he would carry the inside slope straight up to the top of the embankment without turning it up or without putting a vertical wall as shown in Figs. 9, Plate 1. The embankment was paved where that occurred on the top afterwards, so that if the spray should be carried over again it would fall upon a paved road. A large mass of stone was laid on the place, and he believed that now it would be satisfactory. That was one of the dangers of curving the embankment up or putting a wall like that which the waves could strike against and then fly over. Under Mr. Bateman, and also on his own account, he had made some sixty reservoirs during the last 45 years. Two of those were embankments of 100 feet high, and they were perfectly sound and right to this day, holding 95 feet of water at the top. They had not the difficulties in England which were met with in India in dealing with the flood water. It was usual in England to make a large discharge tunnel and let the water pass through during the construction of the dam itself. The difficulty encountered, and which he fully realized, was that, when the work was finished to top bank level, it had to be tested for tightness. After the test of the work, if there

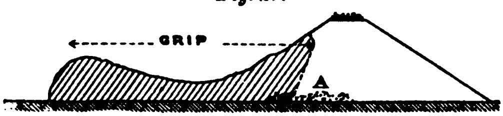
was anything not quite right, it was difficult to get to the work again. The work could not be tested in progress because generally the excavations were carried on inside of the reservoir and the testing would interfere with the construction of the work very materially. In cases where there was rich material, he thought that a 5 to 1 slope was not too flat. In some cases on the Manchester Works, where there were reservoir embankments 3 miles long, and the reservoirs 30 feet to 50 feet deep, he had a 5 to 1 slope, a 4 to 1 slope, and then a 3 to 1 slope; but the 5 to 1 slope slipped out, and it cost about £40,000 to insert burnt ballast. In the first place a flat benching was inserted about 30 feet wide, but the benching slipped out as well; however, the banks were now tight. The 5 to 1 slope with a very rich material was not too flat a slope. He would be inclined to place a bench at the foot of the slope where the material was very rich. There was generally good material for the centre of the embankment, and he placed all the gravel and stony material on the outside, which acted as a retaining wall and then there was no fear of a slip. Mr. Hill.

Sir Guilford Molesworth.

Sir GUILFORD MOLESWORTH, K.C.I.E., considered the Paper an eminently practical and useful one. The Author wisely said that too much reliance must not be placed upon the formulas of flood discharge over the country. Such formulas as could be collected were the best data available for such works, but they were frequently incomplete, and they must be applied with great caution. He might instance two or three extreme cases, which showed how dangerous it was to apply such formulas recklessly. He had sometimes passed the Guggera river (which took its rise in the hills) when it was a raging torrent, and he had the greatest difficulty in crossing it on an elephant. It was between ¼ mile and ½ mile in width, and as far as he could remember, was crossed by a bridge of about ten spans of 40 feet each. One hundred and fifty miles further down the stream was an inconsiderable one. There was a railway crossing, and the bridge had two or three 40-foot spans. The river never reached the sea at all; it lost itself. Another extreme case was presented at Cherrapunji, where the rainfall was between 600 inches and 800 inches in the year, which he believed was the greatest rainfall in the world. Thirty miles away, at Shilong, the rainfall was barely 100 inches in the year. It was impossible to draw any conclusions from such data. Again, in South India the rivers generally took their rise up at the Western Ghauts. The mountains rose suddenly near the western coast, and the country sloped down to the eastern coast.

Sir Guilford Moleswort. The river passed through two districts, the district of the south-west monsoon, and the district of the north-east monsoon. On one side, the district of the north-east monsoon, during the south-west monsoon, there was scarcely any rain at all, while in the western district, on the other side, the rainfall was exceedingly heavy. During the north-east monsoon these conditions are reversed. At the top of the Ghauts; the "sponge" was, as it were, squeezed out, the clouds lost a great part of their moisture, and when they had passed a few miles further on, the rainfall was comparatively small. For those reasons it was very difficult to apply with any degree of accuracy such formulas, depending as they did on the length of the river or the catchment area. He was much interested in the matter of the slips. Of the London clay the late Mr. George Stephenson used to say that it would sooner run up-hill than stand still. He had had experience of it running up-hill when he was engaged in the construction of the low-level line to the Crystal Palace. There an embankment was constructed about 28 feet or 30 feet high. It was tipped in the most rainy season of the autumn of 1853 or 1854, and it went down, as more earth was tipped to keep the embankment to the proper level, practically taking the slope shown in *Fig. 27*. He ran in grips to drain it, and got trains of chalk and filled it in. The slurry of that London clay was so great that a quantity of ballast was tipped on the top by the contractor to keep his temporary way in order, but the slurrying was so great that the gravel found its way during the slip down to the bottom, and gravel was found on the level of the ground as shown at A. The black cotton soil on which many of the embankments in India had been made was a very difficult substance to deal with. It absorbed water, and parted with it again very freely. When wet it was a plastic substance, and it opened out in enormous cracks in the dry season. Those cracks let in water, and it expanded. To give an idea of the amount to which it expanded, he might mention that in one instance a failure had been reported in the foundation of the bridge, and when the engineers went to level from the last bench-mark up to the bridge to see how much the foundations had sunk, it was found that instead of the foundations sinking, the black cotton soil of the embankment on both sides of the bridge had absorbed moisture and raised the permanent way

Fig. 27.



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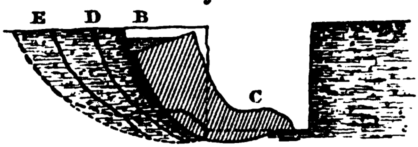
to such an extent that it gave the appearance of the bridge having sunk greatly. Slips, he thought, were due sometimes to chemical changes and disintegration and sometimes to causes which could not altogether be accounted for. Sometimes it was found that the clay would change its character altogether. Such a change he noticed in some clay taken from one of the deep well excavations of the Chenab river in the Punjab. That clay was strong, hard, and tenacious when it was brought up, and so long as it was kept in water; but it dried to a hard consistency like stone. There was great difficulty in breaking it, but when once it had dried and was placed in water, it melted like sugar and became an impalpable mud; its character seemed to be entirely changed. He fancied some slips might be due to a clay which had changed its nature in that manner. There were cuttings which he had to construct on the Punjab Northern Railway which were in clay as hard as rock, and worse than rock to cut through. Blasting it was of little use, but if water reached it, it would run like sugar. The great cause of slips, he thought, was undrained water and unbalanced pressure. He had noticed a good deal the character of the slips, and they generally occurred somewhat in the following way. If London clay, or a similar clay was disturbed by a gullet, it had a tendency to crack in dry weather; it would crack as shown at B in *Fig. 28*, and water would percolate in. There was a tendency for that collection of water to act as a lubricant and exerting to some extent hydrostatic pressure to scoop out the portion below formation which was unbalanced by the removal of earth in gulleting. When the part marked C was gradually removed, the weight was taken off and still further slips occurred as shown at D and E. This went on until the cutting was afterwards found forming a section shown by the dotted line. The only plan to deal with slips in an embankment was to drain them thoroughly, by running grips into the embankment, and by filling them with some substance like rock, brick, chalk, or any other substance which would act as a counter-fort and drain the soil. In some cases it was desirable to burn the clay in the trenches that were cut. This had a double advantage; it formed the material with which to fill the trenches, and it also dried, to a certain extent, the sides of the trench. The profiles shown in the diagrams were

Fig. 28.



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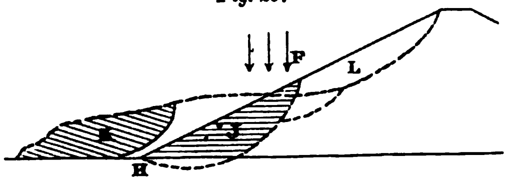
somewhat instructive. The form which they were said to take was somewhat like that shown in *Fig. 29*. If a crack began at F the pressure at that point was not balanced at H, and the tendency was to scoop out the material marked J, which went forward, as it were, into the position shown at K. The layers which were originally horizontal in position were now in the new position tipped up, and then, the weight being taken off, the part marked L, generally followed filling up the void caused by the movement of the mass J, and giving the form so common in slips of that kind. He was glad to see that in India those were left and drained, and he thought the plan was a good one. It left the embankment in the way which Nature seemed to form itself.

Fig. 29.



The Author had shown in the profile a dry stone toe. He thought the material would be much better employed if, instead of being one sloped mass, like that shown in *Fig. 30*, it was either a berm of dry material, as in *Fig. 31*, or perhaps, better, counter-forts running in a short distance and joined, acting as a drainage of the part, and loading the toe of the embankment instead of leaving it, as generally, unbalanced with a sharp slope. The Author had stated that there was seldom any slip on the up-stream: that was easily accounted for by the fact that the foot was always loaded, or nearly always, by water upon it. With regard to the outlets, he must confess a preference for keeping the outlets, if possible, far away from the bank.

Fig. 30.

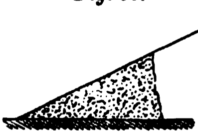
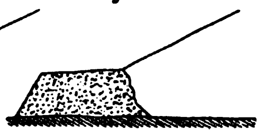


Fig. 31.



He had been a good deal concerned with the village tanks in Ceylon, which were sometimes a few acres in extent, and sometimes some square miles. He had always there, if possible, made a channel in the high ground outside the bank to carry the outlet, and, if possible, placed the sluice in that. Of course in very large embankments it was out of the question, but in moderate-sized embankments he considered it always the safest way, and had many advantages. The earth-work excavated from such a channel was always available for the bank itself. In South India a great

many difficulties were experienced with regard to the tanks or reservoirs, owing to the fact that there were very often chains of tanks, in a series, one below the other; and when one burst, the whole of them went, one after another, and no waste-weir that could be put up would save the tank from destruction. Sir Guilford Molesworth.

Mr. R. B. BUCKLEY noticed that the Author had referred to the silt which was sometimes deposited on the up-stream side of the embankments. In all irrigation works in India silt presented a difficulty in many ways. It was a greater disadvantage in the case of earthen embankments than in that of masonry dams, because when an earthen embankment was made across a gorge the gorge was practically completely closed up to a certain level. Every flood that came down, or every discharge that came off the catchment, brought a large quantity of silt, and the water in the reservoir necessarily rose to a fairly high level, to the dip of the escape that is, or above it, every time there was a discharge into the reservoir. Further, the silty water coming down pressed forward the clear water. The clear water and not the silty water was discharged in the first instance, consequently behind all earthen dams there must necessarily be large accumulations which in time became serious, and might indeed be fatal. But that was not necessarily the case with masonry dams. In the case of Bhatghar, in Bombay, Mr. Whiting cut six of eight large sluices in the bottom of the dam, and he was thus enabled to keep the level of the water in the rains down to a fairly low level. He not only passed the silt through the dam, but did not permit it to be deposited on the higher levels of the reservoir, which must necessarily be the case with earthen embankments. With regard to the question of the puddle-trench, he was afraid there was a fixed difference of opinion between Indian engineers and English engineers on the subject. He thought that most Indian engineers would consider that the right place to put puddle, if it was used, was on the surface of the inner slope of the embankment. English engineers with hardly any exception would prefer to place it in the centre of the embankment. He fancied there was some explanation; it might possibly be that there was very little clay in India at all, and that the experience of Indian engineers was not so good as that of the English engineers, because good material could very rarely be obtained in India. It certainly seemed that theoretically the right place, if a dam was required to be tight, was to make it tight on the face and not in the centre. It was true that by putting the puddle in the centre of the dam the puddle itself was more secure, but he thought it was also true Mr. Buckley.

Mr. Buckley. that unless the puddle was really thoroughly good it was much more dangerous there than it was on the face. It was admitted that it was necessary to drain the base of the embankment and keep it dry—if the inner slope was tight the water could not percolate into the dam. When a puddle-wall was made down the centre it appeared to be a confession that the front of the embankment was no good. If it was not made watertight it was a disadvantage, because it might become saturated with water and thus an extra strain would be put on the embankment. The same argument applied to the puddle-trench below the embankment shown on the diagram on the wall. He should be disposed to put that puddle-trench further forward, because by so doing, water was prevented from getting under the embankment. Surely the water had to be prevented getting under the embankment at as high a point as possible. In reference to the formula of discharge from the catchment quoted by the Author, he had in one or two cases applied it and had found it give results much larger than the actual discharges which he knew flowed off certain defined areas. If, however, it was necessary to have a formula, Mr. Craig's was as good as any. That gentleman had taken a great deal of trouble in working it out, and his Paper[1] was a very valuable one. The Author had referred to the question of the flow off the catchment. It was very difficult to arrive at any correct calculation of the flow, as the discharges varied so greatly for the same areas under almost the same conditions. For instance, in a tank constructed by Sir Alexander Binnie the rainfall on one occasion, on the 18th of June, in 1 hour and 20 minutes was 2·20 inches, and nothing came off at all. On another occasion, the 10th August of the same year, there were 3½ inches (an inch more) in 1 hour and 45 minutes, practically the same time, and half the water came into the reservoir. There were many examples of that kind. In the North-West provinces and in Bengal it was generally safe to allow a discharge of 3 inches off the catchment in 24 hours, if the catchment was 10 square miles or less, gradually decreasing it to ½ inch or even as low as ½ inch, in areas of 2,000 square miles. That experience was entirely broken in 1885 by the famous accident to the Kali Nadi aqueduct on the Lower Ganges Canal, when there was a rainfall of 17 inches in one day and 3 inches in the next, making 20 inches falling in 2 days but in one period of 24 hours, and the flow off there was no less than 3 inches in 24 hours from an

[1] Minutes of Proceedings Inst. C.E., vol. lxxx. p. 201.

area of about 2,300 square miles. That flood was regarded as unprecedented. In dealing with the flow off the catchment, he thought as much data as possible should be obtained applicable to the country to be dealt with, and judgment made accordingly. Great importance necessarily attached to the amount of rain which fell. He confessed astonishment at the first example given by the Author. It was stated that there was a rainfall of 80 inches in four days in October, 1884, in the valley of the Lower Ganges Canal. The Lower Ganges Canal was in the valley of the Ganges, a little above the place where Mr. Buckley had lived for a good many years. The annual rainfall of the zone near the Lower Ganges Canal was between 40 inches and 50 inches. A rainfall of 80 inches in 4 days was very great indeed. The noted flood which destroyed the Kali Nadi aqueduct on that same canal caused great destruction. There were 20 inches of rain in 2 days, which was very different from 80 inches in 4 days. Only last July he had to deal, rather lower down in the valley of the Ganges, with a flood that occurred in Patna. The rainfall was almost unprecedented, certainly for the last 25 years. The fall amounted to 15 inches or 16 inches one day and 7 inches or 8 inches the next—25 inches in 2 days—practically half the rainfall of the year in either two or three days. He found from the India Office returns of the rainfall in the North-Western provinces, that in the whole year 1884 the rainfall only exceeded 80 inches in five stations; and in the month of October, 1884, though the largest rainfall of the whole month was 24 inches in one place—in the hills—the highest rainfall generally was 10 inches or 11 inches, and that only in some 16 places out of 250 places or 260 places altogether, some of which, he knew, were in the valley of the Lower Ganges Canal. If 24 inches was the maximum rainfall for that whole month, and 80 inches really were registered in 4 days, such rainfall must have been very local indeed. He could not help thinking that there must be some mistake about the matter. During the late famine in Bengal he was astonished to see the wonderful results obtained from irrigation works. The whole of the districts of Chumparun and Durbhangah were very seriously affected, and it was his duty to ride through great parts of those districts and also the districts on the south of the Ganges, where there was a large irrigation system taken off the Sone River. He rode for miles through rice-fields where a man literally could not have filled his hat from an acre. In many places the crops were completely gone. On the Sone canals, where the water had gone,

Mr. Buckley.

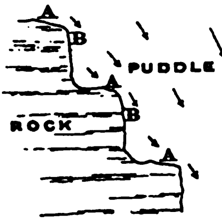
Mr. Buckley. the whole country was green and bright and verdant; the people gathered from their fields 25 maunds, 30 maunds, even 35 maunds to the acre; but those who had not irrigated obtained very much less, and in some places nothing at all. In another instance in the north of Bahar, where there was a small irrigation work, it was calculated that the value of the produce saved by that little work was equal to between twice and three times the entire cost of the work. The work paid nothing at all, and the Government did not receive a penny of revenue. The great Sone Canal system, which carried some 6,000 cubic feet a second on to the fields in the famine year, saved between 300,000 acres and 320,000 acres of crops; and they placed some 300,000 tons of grain available for feeding the people, which would not have been there if those works had not existed. In the unirrigated famine districts there were empty threshing-floors, but in those parts where there was irrigation the grain was piled up, and the people were not only happy, but wealthy, because while famine brought distress and death and sorrow to people who had no crops, it brought health and wealth to those who had them, because they sold the grain for double or treble the money they would have received in an ordinary year. The Government of India had for many years past pursued a steady, persistent policy with reference to irrigation works. It was Lord Mayo, he thought, who first initiated the system. For many years 50 lacs of rupees were given yearly for constructing productive irrigation works, with borrowed money. Some years ago it was increased to 55 lacs, and lately it had been increased to 75 lacs. The total amount of money spent on productive irrigation works was 28 millions X rupees. Those works for the last ten years had never paid less than 3½ per cent. In 1892 and 1893 they paid 5 per cent.; in 1894, 4½ per cent.; in 1895, 6 per cent; while in 1895–6 the works in Madras paid 7 per cent.; the Punjab 5 per cent., and the North-West Provinces 3½ per cent. The whole of the money the Government had put into the irrigation works brought in from 3 per cent. to 4 per cent. or more, and they could borrow at 3 per cent. He did not mean to question the wisdom of the Government in progressing thus slowly with those great works. No doubt it was well to go slowly and steadily. Still less would he question the wisdom of their policy in granting very much larger sums to the railways. There had been many discussions with regard to the advantages of irrigation works and railways in preventing famine, and he thought it might be said that the discussion was now fairly finished. No irrigation works would entirely prevent famine except in their

own neighbourhood: railways would if they were sufficiently extended over the whole country. He hoped the time had come when the Government would see their way to spending more money on irrigation works. They could borrow at 3 per cent., and surely it would pay them to spend it and receive interest at 4 per cent. The works not only paid, but they brought happiness and contentment to the people, and established the main object of British tenure of India—they established England's wish to do what she possibly could for the prosperity and happiness of the people. Mr. Buckley.

Mr. G. F. Deacon thought the Paper represented the result of much careful observation. Many of the conclusions, however, were limited to the conditions which obtained in India and could not properly be applied by English engineers. With regard to the puddle-trench, it appeared that an artificial puddle was produced consisting of 3 of black "cotton soil" (which he understood to be highly argillaceous, but liable in its crude condition to flow) and 2 of sand. The best puddle-clay of the boulder-clay formation consisted of about the same proportions of argillaceous material to silicious sand, and so long as the sand was not in a greater proportion than 50 per cent., the clay not only stood well, but was quite satisfactory for water-stopping purposes. It would neither slip readily nor turn into slurry. Considerable care appeared to be taken in the artificial mixing of the black soil and sand for the formation of the puddle-trench, and if, instead of the massive hearting, a puddle-wall, such as that adopted by English engineers, were formed with this material it appeared to him that a better and easier result would be obtained. Now, concerning the best position for the formation of the watertight septum. If it were put next to the water-slope, as suggested by a recent speaker, its area would be at least three times as great, and that could not be a good thing. By putting it in the centre of the dam, the area exposed to percolation was obviously diminished to the smallest possible amount. Moreover, it was well known that when near the inner slope the puddle was liable to dry and crack during summer weather, and therefore to leak when the water rose again. He thought there was a very proper consensus of opinion in England that to place it thus would be bad practice. It was a method that had been largely adopted in old times for mill reservoirs, and it had failed over and over again. The large volume of impermeable mass in the centre of an Indian dam, of such construction as had been placed before the Members, would only be practically employed where labour was Mr. Deacon.

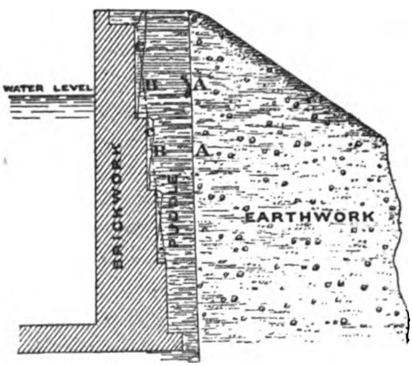
Mr. Deacon. exceedingly cheap, as it was in India. He did not understand the limits which the Author proposed to put to the adoption of steps in connecting earthwork as illustrated on p. 149. With the connections shown in *Figs. 1* he entirely agreed, but the adoption of the arrangement in *Fig. 2*, either for puddle on rock, or new puddle on old puddle, had, he believed, frequently led to leakage. When the new work was in the process of settling down over the nosing of the steps the motions took place in some such directions and with some such relative intensities as indicated by the arrows in the sketch, *Fig. 32*. That motion, however small its amount, ensured nearly the full pressure due to the column of puddle against such surfaces as A A, while just below the nosing, as at B B, the pressure was greatly reduced, and a hollow was sometimes formed.

Fig. 32.



The same principle was involved in a common but defective mode of construction of some reservoir walls or embankments. Thus in *Fig. 33* it was manifest that the puddle and earthwork at A would settle more readily than that at B, with the result that the puddle parted from the brickwork or masonry, sometimes leaving a space of several inches as indicated at C C in the *Fig.* He had effectually brought puddle pressure against the back of the wall and thus cured the leakage in such cases by plastering up the set-offs to the dotted line so as to obliterate the angles and present to the puddle a sloping side against which its weight securely wedged it. The same straining action and separation occurred when puddle was keyed into deep vertical chases in brickwork or masonry. The friction between the puddle and the sides of the chase tended to hold up the puddle within the chase while that further removed from the chase settled down, with the inevitable consequence that either the puddle was drawn away from the back of the chase or sheared off at the face thereof. The danger of the method

Fig. 33.



shown in *Fig. 2*, unless properly limited in its application, led him (Mr. Deacon) to refer to the consequences which he had actually seen in practice. A comparatively thin watertight septum of concrete in lieu of puddle had been referred to. Such concrete walls in the hearting of earthen dams were uncommon in England, but were common in America, and he had seen several. He had not heard of a single failure in such a structure. A great deal depended on the earth being carried up uniformly on the two sides, and the prevention thereby of any serious lateral pressure. With all the Author had said of the importance of thorough draining of the whole dam on the down-stream side of the puddle-wall every hydraulic engineer must agree. More information about the experiment described at p. 138—the impermeability of clay in a pipe 8 feet long—would have been interesting. The pressure was not given, and it was not clear how the measurement of the percolation was attempted. If it was done by simply watching the outlet, the result might be very deceptive. The evaporation in a warm climate might be sufficient to account for considerable loss. The measurement ought to be made from the inlet, as such measurement would include the evaporation at the outlet. It was not an uncommon error to suppose that puddle was impermeable because, when exposed to the air on one side, it dried and no sign of percolation appeared, the fact being that water was percolating it the whole time. In reference to the best section for earthen dams referred to at p. 158, he agreed as to the desirability of diminishing the slope towards the bottom or increasing it towards the top. There could be little doubt that the construction of berms or benches on the outer slope had risen from the knowledge of the older engineers that it was necessary to add weight to the toe, but he never could see why that should be done in steps. It would be just as rational to add to a girder by steps for the purpose of increasing its depth. He thought the Author's description of the mode in which the foundations of the Yarrow dam—one of the Liverpool Corporation Waterworks dams—were drained, might be a little misleading. It might be supposed that the puddle itself was drained in the way described, the fact being that it was merely the rock below the puddle that was drained by the stand-pipe. Over the spring which was found at the bottom at a very considerable depth—about 160 feet—the precaution was taken of placing a thick bed of concrete to prevent the possible washing of the puddle, and from below this concrete the spring water was conveyed away in that manner. That was a very common expedient in England, Mr. Deacon.

Mr. Deacon. and a very desirable one in such circumstances. The Author had stated two formulas for the flow off the ground, but did not appear to recommend the use of either. He (Mr. Deacon) ventured to say that on small areas the use of either might lead to disaster, as the possible excessive rainfall on the smaller area was not taken into account. There was a broad distinction between the maximum intensity of rainfall over a large area, exceeding, for example, 10,000 acres, and that which might occur over a small area of 1,000 acres or 2,000 acres. In this country and over the larger areas, probably from 10,000 acres upwards, he thought the older engineers had been right in fixing the limit at something like 300 cubic feet per second per 1,000 acres. Over smaller areas he had certainly known two cases in which it was three times that amount, and the mean rainfall would indicate no such excess.

Sir Douglas Fox. Sir DOUGLAS FOX was sure that the Institution highly appreciated the very important Paper which had been laid before them. Dealing as it did with work in India, it was specially valuable because of the very great forces which had to be contended with in that country. His own experience in India had been in connection, not with hydraulic work, but railway work, but the result had been to give him a very great respect for the hydraulic engineers. Unfortunately, in India the two departments which had under their paternal care the irrigation bunds and tanks and the railways were not identical, and they did not always help one another so much as they might. Something had been said about the power of Indian floods, and he might mention a very extraordinary example that occurred on the South Indian Railway. A bridge across the Gingee river, on the railway which runs into Pondicherry, had seven spans of 150 feet of lattice girders, built on masonry piers, and supposed to be 10 feet above the highest level of flood-water. There was a very extensive irrigation tank above the bridge on the river. A heavy rainfall came, but the water would certainly not have touched the superstructure of the bridge if one of the bunds had not burst and brought down a very heavy freshet through the bridge. The result was that the water rose not only the 10 feet, but almost to the top of the lattice girders. Still, no harm would have resulted if it had not unfortunately been that the bund had upon it a forest of trees, and those trees were brought down by the flood. They piled themselves up against the side of the bridge and swept six out of the seven spans off the piers into the bed of the river, but so little damaged the piers that the bridge was rebuilt without their being reconstructed. That was a

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very wonderful instance, he thought, of the power of an Indian flood. In crossing the rivers of South India great difficulties had been encountered in dealing with the inequality of the flow. Several of the rivers there, the Panor, the Palar, and others, as had been described by a previous speaker, were large rivers higher up, but, by the time they got to the sea, some of them, at any rate, almost disappeared, partly in consequence of the large quantity of water taken off by the irrigation channels and partly by evaporation. Those rivers were very wide between their banks, some 2, 3, or 4 miles wide, and although the sites for the railway-bridge might be very carefully selected at any part of the width, it did not matter where, the stream might be very kind for about a year, and then might turn off, and not pass through the bridge at all, but go through the railway embankment. One result was that some floods in that part of India resulted in delays to the traffic of 3 and even 4 months at a time. It was decided in certain places to let the flood work its wicked will without interruption. The railway was being lowered so as to do away with a high embankment, and although stoppage of 4 or 5 days might occur, sometimes even up to 10 days, in consequence of the rails being covered by water, yet that was far better than the present state of things, which meant a delay sometimes of 3 or 4 months. He had had an exceptional experience during the last few years of high embankments in bad material, and he should like to support a great deal of what had been said by Sir Guilford Molesworth. He was convinced that success in the difficult matter of constructing a stable embankment where the material was slippery depended largely upon foresight at the commencement. Often—much more so in railway matters than for important hydraulic dams—the arrangements for earthworks were rushed, and a good deal of the precaution which was necessary was omitted. He agreed that the secret of success in dealing with bad material in earthwork was drainage, but drainage applied before and not after the damage had occurred. He was a strong believer in the thorough drainage of the site of the embankment to begin with and the removal from the site of any soft material that might be found, especially near the toe of the slopes. In the case of deep cuttings it was most important to cut heading drains of considerable size and depth to divert the natural or artificial drainage of the country and prevent water finding its way down the slopes. He had never been able to see the advantage of putting a flat surface or berm in the middle of a slope; he thought it was far better to use the distance in

Sir Douglas Fox. flattening the slope from top to bottom and making one continuous surface, than in steepening the intermediate portions, and then having a flat surface on which the rain could fall, and through which it was very liable to percolate and find its way through the bank or into the slope of the cutting. One common cause of injury to some of the embankments in England had been a false economy in fixing the slopes to begin with. Nothing caused the engineer more anxiety than the attempt to balance the cost of a flat slope against the economy of maintenance, but he was convinced from his experience that it was wise to study the slopes which Nature had chosen for herself where she was free to act, and not attempt to steal a march upon her, because if that were done, Nature would assert her rights. If the members travelled over many of the railways in the coal districts, they would see how the maintenance Engineer had suffered because of an attempt to economize on the part of the Engineer who had had charge of the construction. He was a strong believer in being very careful that the slopes were not too steep. He thoroughly agreed with what had been said in the Paper about dealing with very exceptionally high slopes such as were described in the Paper, and which he had had on one or two occasions to deal with in railway works in England. There was one instance where the embankment was just over 90 feet high, and the material was very doubtful. The bank had to be tipped in a gorge that was sloping very considerably towards the sea. There the compound slope, which had been spoken of, was adopted of $1\frac{1}{2}$ in the tops, flattening down to 2 in the middle, and to 3 in the lower part of the bank; and it was most successful. If the history of slips were studied, it would be almost invariably found that the material assumed something like that kind of figure, that is to say, it flattened itself out at the bottom. With reference to dealing with slips he did not think it was possible to lay down any empirical rule; each slip must be dealt with according to its special circumstances. Then again there came in the question of drainage. If water was found in the bank and could be tapped and let out, a great part of the evil would be probably cured. He agreed that a great deal of good could be often done by cutting trenches, as most of the railway Engineers had learned, and as they carried out in practice very largely, and filling them with either burnt clay, broken stone, or some other material, which would allow water to percolate. More benefit thus accrued than by putting in expensive retaining walls at the toe. He thought the one thing to be avoided, if possible, was the mixture, in the construction of embankments, of side and

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end tipping. That had often been the cause of a serious injury to earthwork. Side-tipping, if it were properly arranged, could be carried out with safety, and so could end-tipping; but it required considerable care if the two were combined. He agreed as to the importance of burning a slip. That was very largely carried out on the main railways of England at present. It was often a cheap and satisfactory way of curing a slip, especially in a cutting, but he was convinced that the two great things needed, if it were desired that earthworks should stand, were to drain them well and to take care that the slopes were not too steep.

Mr. Latham.

Mr. BALDWIN LATHAM thought it should be remembered what it was that made material watertight. A rock was watertight if it was non-absorbent of water; but a soil was not watertight unless it would absorb an enormous quantity of water, so that to make a dam watertight a soil had to be selected which contained within it a very large proportion of water. All those soils which contained a large proportion of water by absorption had a very slight angle of repose. They were in an extreme state of instability. So that if a material of that kind was used in an embankment, the proper place to put it was certainly in the centre of the dam, where drier materials could be put on each side to support it and prevent it from spreading out. In the particular section shown in Fig. 8 of the black soil mixture, it would be seen what a large proportion of the bank was made of a material which must naturally be in an extremely unstable state. By no possible means could that soil stand at a slope of 1 to 1 on the outer slope, or, as shown in Fig. 14, 1½ to 1 on the inner slope. The only thing that kept the hearting from slipping, therefore, was the weight of the material of a drier description put upon it on both sides. That, to his mind, was a radically wrong mode of construction. Where a watertight material had to be introduced, it had better be used only in such quantity as was absolutely necessary, and packed up to prevent that element of instability, which existed, more or less, in all embankments, coming into play. The strong reason why it was undesirable to put a watertight facing on the inner slope of the dam was obvious. A clay soil of sufficiently watertight character by no possibility would stand on the slope of the dam at 3 to 1, which was the ordinary slope used for the interior of the reservoir. In fact, it was known that some clays, like the plastic clay, would not stand at slopes of 7 to 1. The blue-lias clay often would not stand at 5 to 1. A reservoir embankment made of it had been known to slip which had a slope of 4 to 1. So that if a material like clay

Mr. Latham. was placed on the inner face of a dam in direct contact with water it would immediately slip off, and therefore the dam would no longer be watertight. In the old dams Telford used the method of introducing clay on the inner face of the dam, which theoretically no doubt was the correct mode of making a dam, because, if the inner face was watertight, the weight of water, the prism of water, pressing on the face of the dam fixed the dam upon its seat; otherwise the whole of the inner slope, if it was porous up to the puddle-wall, had little effect on the stability. The whole stability against a forward movement almost entirely depended upon the puddle-wall and the outer portion of the dam. Telford, in order to guard against that evil of the liability to slip, invariably mixed gravel with the clay, rounded washed gravel, which gave the clay itself a greater stability than it otherwise would have by itself, and to some extent overcame that tendency to slipping. But the dams which were made in that way were not such as were made now, and there was certainly an element of danger in using material of that description on such a steep slope as it was necessary to use in the economical construction of a dam required for impounding water. It appeared that the Author had laid down that it was undesirable to use any sharp steps in an embankment. That was true with regard to every other part of the embankment, and therefore the Author was preaching one doctrine and practising another, because the whole of the filled-in final stage consisted of a series of steps. In advising the filling in of one of the Indian embankments, Mr. Latham took great care that everything in an embankment should be wedge-shaped, so that, as it settled, it would wedge itself tighter and tighter. That was the great principle to be adopted in both the trench and in filling in the gap in the embankment itself. With reference to the depth of puddle-walls and the material found below the puddle-wall, he thought no hard and fast rule could be laid down. The puddle-wall might be quite deep if it was only 2 feet, provided it was sufficiently broad and the material below was absolutely watertight. It might have to go down over 100 feet, as he knew from his own experience, and then a question came in with reference to concrete. Concrete had been largely used instead of puddle in a trench, but unfortunately concrete had failed in many instances. He had had, in the course of his experience, three examples where a dam had leaked from the introduction of improper concrete. In one case where a block of ordinary lime concrete was built across the puddle-trench in order to

Mr. Latham.

carry the outlet culvert across the trench, it was so porous that the water passed through it and passed by the side of it and washed away the material, and the dam leaked. In another case, that of the Fylde Waterworks, where the concrete was put in in layers, each being allowed to set before the next layer was commenced, the concrete was tipped in from a height from the top of the dam. The result was that on the beautiful table that had been prepared for it, all the big stones went down to the bottom, and then the layer was worked up. When that was set the next layer began, and so on, and when the dam was finished it was found to be as porous as a sieve, and every bit of the concrete was afterwards blown out. He had had a somewhat similar experience quite recently on the Llanvaches reservoir, Newport, Mon., waterworks, where upwards of 10,000 cubic yards of concrete were put into the dam, and it was found to leak at most joints. It was not watertight. The material was extremely hard and durable, 4 to 1 concrete, and in that case he was putting a face on it next the water. In that Llanvaches reservoir the whole of the beds tilted at a considerable angle in the direction of the dam, and to take that amount of material out and to re-timber the trench again would have cost about £40,000. The question was how to deal with it without having to very heavily timber it. He had been carrying it out in sections, a joint being left at every point 30 feet or 40 feet in length, and the concrete when completed would be 3 feet in thickness. The concrete had been cut down partly on the rock and partly in the concrete. It was intended to render the face down to the full depth, and then to fill in with concrete. It would be seen that the joint was made of a peculiar form, so that if there was any contraction or expansion it would tighten. The jointing of the rendering and the jointing of the concrete which was put into the work were not in the same position. He did not think it was possible to lay down any general rule, but in making a test of the concretes as to the thickness which ought to be used, a large number of tests were made under pressure, and it was found that with really good concrete of 4 to 1, even a 6-inch slab would stand a pressure of over 300 feet without any difficulty, so long as they ensured it being sound and not broken up in the screwing up of the apparatus. He had great confidence in concrete, but he could not conceive that it should be used in the position which had been recommended by the Author. Concrete was extremely valuable when below the ground and not exposed to the influences of heat. If a slab of concrete was put on the outer face of the

Mr. Latham. dam it would crack in all directions, and would look the most unsightly piece of work in a few years. He thoroughly believed in concrete for pitching, and it was intended to pitch the slope of the reservoir he had mentioned with concrete blocks instead of using stone. Men could be employed on wet days to make the blocks, with the great advantage that the blocks could be grooved in the side, so that when the whole of them were grouted in position they formed a homogeneous mass completely protecting the face of the bank and not liable to show any cracks, and, in fact, formed a much more perfect work to all appearances than even an ordinary stone pitching. Moreover, in order to protect it from the wash of the waves, a deeper block might be put in here and there, so that the wave would run up it and be broken near the top of the water-line instead of flowing up the smooth face of the dam. In all those cases every man must use his own discretion. He had seen berms used in reservoirs, but he thought if, instead of using a berm, the same material had been spread out so as to flatten the slope of the dam, it would have made a much better dam. The question of drains was one of extreme importance, but he looked with very great suspicion on all drains which were brought up near to a puddle-wall. He did not like to have a work buried where it could not be got at to see what was going to happen. If such a drainage as had been proposed and shown in Figs. 9, 10, was carried out, if any fine material by any means got washed out of the bank, it would pass into the drains and lead to settlement at the point where it could not be got at without extreme difficulty. If the outer slope had sufficient stability, so that it was well within the angle of repose, any water which passed into it would naturally flow out of it by natural drainage, in the same manner that water flowed out of the side of a hill. To put drains in, close alongside the puddle-wall, as had been suggested in the Paper, in his opinion, was a proposition that would be likely to lead to failure.

Mr. Raworth. Mr. Raworth said he should like to ask the members of the Institution one question, and that was: Why did they not get on a little quicker with the matter of dams? When he was quite a small child the Bilbury reservoir at Holmfirth burst, and great loss of life ensued. Later on the Sheffield reservoir burst, within his very vivid recollection. He was prepared to state that everything that had been said that evening was most fully discussed and most elaborately thrashed out exactly thirty years ago. He did not think they had heard anything in the discussion that had added one iota to their knowledge of the subject under discussion.

Mr. E. P. HILL was impressed by the difference shown in the Paper between the practice of engineers in England and those in India. In England, at any rate, in constructing dams, the function of the dam was to divide the water above the dam from that which was below, and if, after the work was completed, any leak occurred, an engineer would be somewhat disconcerted by it. But in India it seemed to be entirely different. There the trenches were not necessarily carried down to a watertight foundation, and leakage was looked upon to a great extent as an ordinary event. So much was this the case that in the Paper an elaborate system of drains was described for taking away the water which had escaped after passing under or through the dam. No doubt in England the foundation of the outer slope was drained, but as Mr. Latham has said, the drains were not generally carried very near the puddle-wall. The idea was merely to take away water which originated on the outside, and not to take away water which had passed through the dam. It might be that the question of cost accounted for the difference of practice. In England it was the cost of the water that was looked at. When they had received parliamentary powers to take water from a valley they wanted to utilize the water in that valley to the utmost extent, and therefore they went to great expense in order to make the dam watertight; but in India there was apparently plenty of water but not so much money, and the cost of a dam was the principal thing to have regard to. If a leak occurred in English works the corporation or water company for whom the dam was constructed would look askance at it, and would probably be very much dissatisfied. If it were a leak of 100,000 gallons a day, the corporation or the company would probably say, "There goes a quantity of water sufficient to provide for a population of 5,000 people;" but in India they would say, "To attempt to stop a leak, or rather to avoid the risk of such a leak, would have cost us perhaps £20,000 and the digging of a deep trench," and they accepted the position with equanimity so long as the leak was not dangerous, and, if the water came out clear below the dam it showed it was carrying away no material, and there was no danger. In the Paper there was a remark made about timber trenches being undesirable. "Timbered trenches, owing to their vertical sides, are objectionable for puddle-work." He thought he was right in saying that all the trenches in this country were timbered trenches, and that they had vertical sides. They had not vertical ends, but there was no reason why the sides should not be vertical, and he thought in this country they always were. Mr. Hill.

Mr. Hill. The puddle was put in of the consistency of putty, and the tremendous weight of the puddle-wall vertically above it squeezed it to such an extent that there would be no open spaces as described. Parts of the trench in this country were generally over 100 feet in depth, and it would be obviously impossible to slope the sides from top to bottom in the way described in the Paper. Near the top they were sloped in order to receive the base of the puddle-wall, and for that part they were like the sections shown of the Indian dam. He did not follow the advantage of the two trenches mentioned in the Paper. It seemed to him it would be very much better and more scientific if attention was concentrated on one trench, and that trench made as deep and wide as necessary, but only one trench being made instead of two. With regard to the concrete in the trench, his firm had used concrete for a great number of years, and they had never had any difficulty in making it watertight. They had not a single case in which the concrete leaked. Very great care was of course necessary in its inspection, and they had inspectors at the top and bottom of the trench and then it was very good. When it required so much care it was some source of anxiety, and latterly his firm had used a concrete shoe about 5 feet thick at the bottom of the trench and refilled with puddle above it. That made a very satisfactory piece of work. Something was also said in the Paper about water always passing through the puddle. That seemed to him a very surprising statement. In all the cases he had seen, and he had seen a good many in England, of reservoir embankments with puddle centres, he was not aware that water passed through the puddle at all. It seemed to be accepted by the Author that it should do so, but if water passed through the puddle it would probably bring away the material, and either the puddle wall would settle or sand or something of that sort would be carried in by the water and make the leak worse than it was. In India they put in the material in very thin layers, while in this country the puddle was generally put in in about 8-inch courses and then cut with tools about 12 inches in length, so that in cutting it the tool always entered the course immediately below. There was a point in the Paper with regard to the self-drainage of watertight material. The watertight material was wanted not to drain but to retain the water, and if that material had a self-drainage it would only take the water out of the reservoir and the dam would not be tight. There was also a statement that French engineers considered dams above 60 feet as unsafe. Sixty feet was almost the minimum for that class of embankment in this country. In

some cases it went up to 90 feet or 100 feet above the level of the brook, and those dams were perfectly safe. The last speaker had mentioned something about the Bilberry dam. The accident to the Bilberry reservoir was caused by the dam settling, and the waste-weir being in the form of a tower in the middle of the reservoir. The bank settled, owing to leakage, and the water went over it instead of the tower. There was another surprising statement in the Paper, which might be quite right in India, but did not seem to be quite right in England. The Author stated in the Paper that the inner slope strongly saturated with water was very dangerous. Almost every dam in this country had the inner slope saturated with water, and there was no danger at all. The dam was perfectly safe, and there seemed to be no reason why it should be in danger. What the Author called compound dams, as far as he was aware, was the ordinary type of dam. In this country the puddle-wall was always put in the middle, which was the vital part of the dam, and backed up with most retentive and close material, and outside that, to help to keep those materials in place, the most stony material was put. That, of course was a compound dam, although not having a stone toe. With regard to the stone toe being covered with concrete to prevent buoyancy, he could not follow that, for directly the reservoir was drawn down the concrete would crack in all directions. And further, he did not see any plan for keeping the water out of the base. If the water was admitted to the base, of course the concrete went for nothing so far as preventing buoyancy was concerned. A remark had been made by two speakers about the vertical wall at the top of the pitching. He quite agreed with everything said on that subject. It had been found in England a most undesirable thing, for the reasons stated. The last point was the tunnel *versus* culvert. In his firm's practice a tunnel was always used now, instead of a culvert as formerly. A culvert, if inserted through the centre of the dam, had to stand an enormous weight on the top of it, and if the sides and bottom of the culvert-trench were absolutely rigid, so that the sides of the culvert could not spread, and the bottom could not settle, no doubt it would be perfectly satisfactory. As a matter of fact the sides and the bottom were never rigid, and the culvert always cracked. Now his firm put in a tunnel round the end of the dam, and always carried the puddle trench below it. They always carried the tunnel where it crossed the dam on a concrete pillar with grooves round it, and that made a very satisfactory piece of work. They had never had any trouble since then. In connection with Mr. Hill.

Mr. Hill. the subject under discussion there was nothing new to be said. It was emphatically a case where, if anyone was going to construct a dam and asked for the best means of doing it, one would be inclined to say, "Ask for the old paths, where is the good way."

Mr. Strange. Mr. W. L. STRANGE, in reply to the Discussion, thanked the members for the favourable reception accorded to his Paper. The steep water slope, $1\frac{1}{2}$ to 1, used in Madras dams would not be safe to use with Deccán soils, and he doubted if it could be adopted anywhere except for small heights. He considered Mr. Craig's formula for the run-off from a catchment the most scientific yet advanced, but, as mentioned in the Paper (p. 173), would prefer to rely upon the results of experience. As explained by Sir Alexander Binnie, the term "selected material" in English practice was applied to the material used to obtain watertightness, whereas in Western India it was applied to that employed to obtain stability. Black "cotton soil" had many deficiencies, but it was the only argillaceous material available, and its defects had to be made good by the use of girt. The wall on the top of the embankment had been put forward by the Author; it had not yet been used in Western India, and it would appear that English engineers were opposed to it. In his general scheme for the whole reservoir the toe of the wall would only be subjected to wave-wash at the very close of the monsoon, when there was but little chance of storms. Up to this time the height of the water was restricted by the "stepped waste-weir" adopted. He was modifying the section to one with a water slope of $\frac{1}{2}$ to 1 and rear slope of $\frac{1}{4}$ to 1 battering upstream to prevent it parting from the dam. With its wide foundation formed after the dam had attained practically final consolidation and with proper care to secure the toe he considered it safe, and it had the advantages of some economy, complete protection of the top of the earthwork, and lightening the dam. Cutting off all leakage by the puddle-trench was desirable, but in all the works in Western India he had seen it had been found impossible to effect, although deep puddle-trenches had been constructed. If the depth, section, and nature of filling of the trench were sufficient to prevent a dangerous amount of subsoil percolation further expense need not be incurred in somewhat reducing the leakage. A very small increase of storage depth would compensate for the loss by leakage at less cost, or pick-up works to recover it could generally be cheaply constructed. He was glad to learn that Mr. Hill had successfully drained puddle-trenches, as he considered this very desirable. The varying effect of rainfall and the treacherous nature of black "cotton soil" accounted greatly for

the difference between English and Indian designs for dams. The "cotton soil" was far inferior to good English clay, while in most situations it occurred in great abundance. Undoubtedly the safest form of outlet was a headwall across an open channel outside the dam (p. 183), but its use was economically confined to small works as described. He thought the drystone toe as designed better than a berm, as it more directly supported the dam, and it lent itself better to the method of closure proposed. He had quoted the rainfall on the Lower Ganges Canal from Mr. Wilson's book. The amount was so excessive that he could only attribute it to a cyclone (Appendix II, p. 195). He had heard of 37 inches being registered in two consecutive days at Máhábleshwár on the ghaut watershed, but that was a very different situation from the plain of the Lower Ganges Canal. He agreed with what had been said as to the puddle wall. Variations in run-off from a catchment were due to differences in the intensity of rainfall and to the state of saturation of the ground. He agreed that the cheapness of Indian labour had permitted the large mass of the Indian dams to be carefully made with impermeable material, but it would seem that with the great mechanical facilities available in England the cost of the same form of construction would not be excessive there, and would be amply repaid by the greater security afforded by a homogeneous and well consolidated embankment. He accepted Mr. Deacon's clearer explanation of the superiority of earth through which water percolated than that in which it stagnated. As regarded further details of the experiment with a pipe filled with clay he would refer to the article quoted. It was therein stated that the greater the pressure of the water the more satisfactory were the results. He presumed the percolation was measured from the downstream end of the pipe. Even allowing that evaporation from it might conceal the fact of some permeability the amount of such leakage would necessarily be so small that the material might, for practical purposes, be considered quite staunch. Mr. Strange.

He would submit that pressure and not supersaturation was necessary to increase the watertightness of soils. Clay soils would require lateral support. The section of the dam Mr. Baldwin Latham had criticised was not one that the Author had advocated. It was, however, not so bad as it appeared, since both the hearting and casings were carried up together and were uniformly and thoroughly consolidated in construction. The explanation of the apparent discrepancy between the Author's recommendation not to use steps in construction and his showing them in the closure

Mr. Strange. of the gorge was that the former had to be aimed at, whereas the latter was a slight divergence necessitated by practical considerations. The whole dam could not be constructed at once on account of its enormous quantity. The closure sections were therefore united with the rest at low slopes not exceeding 10 feet in height, separated from each other by intervals of from 25 feet to 50 feet, and the junctions were supported by the strong drystone toes. The small and distorted scales of the drawing prevented this being shown clearly, but the whole of his arguments were in agreement with Mr. Latham's recommendation to have everything wedge-shaped. Concrete blocks, as proposed by Mr. Latham for pitching, would no doubt answer, but they would be much more expensive in India, and not so durable as hard boulder trap stone. What the Author had called concrete on the drawing was described on p. 150 as a concrete packing of the pitching, and, although he had not actually tried it, he thought it would be a not very expensive improvement on the ordinary drystone work. On p. 163 he had mentioned pure concrete, but would prefer the concrete-packed pitching for large works. Where stone in close-fitting blocks could be obtained cheaply that was doubtless the best form, and the pitching of the Dhupdál weir flanks, thus executed, would be difficult to improve upon. No doubt drains buried below the heart of the dam, as proposed by the Author at the rear of the puddle-trench, could not be attended to after the completion of the work, which was a disadvantage. However, he did not see how they could choke if laid on a hard bed and cased with fine filtering material as proposed. Natural springs ran clear, and it was seldom they had vents as large as those recommended. Without the casing such drains would indubitably choke. He agreed that the question of cost should be taken into account when settling the dimensions of the puddle-trench. The usual practice in India was to found the puddle-trench in sound rock, but he did not consider it essential to go to great depths and expense to attain this if a moderately deep trench could be bedded into a sound and fairly impervious stratum. The compensation for extra leakage could be cheaply obtained by a slight increase of storage. The vertical sides of a puddle-trench were objectionable as a very small projection in them would divert the clay from uniting with the side lower down, and a cavity would be produced in which water would collect, and would in time exert its full hydrostatic pressure. He had mentioned that double trenches had been used at river crossings, but he had been careful to explain (p. 134) his objections to this system, and to recommend a deeper and wider trench—a

course approved of by Mr. Hill. There was no question but that water passed through Indian puddle, and, although he was aware that English clay was a greatly superior material, he was surprised to learn it was absolutely staunch. He would be less surprised to learn that the leakage from it was carried off, unperceived and underground, for considerable distances through the stratified layers which were plentiful in England, but were rare in the Deccán. The self-drainage of the rear of the dam recommended dealt with a very small quantity of water, but it was essential to pass that out and not to imprison it in the dam. He desired to alter his statement (p. 161) that the saturation of the up-stream slope of the dam was "very dangerous" to "very undesirable." Such saturation must diminish its stability and make it as safe as a dry one; it must be flattened, and more material must be used. The drystone toe as designed was practically solid, being packed with clayey murum (p. 162), and water was kept out of the base by the concrete toe wall which was founded into rock. Experience in Bombay had shown that culverts under the dam were quite safe, but, to make assurance doubly sure, he had recently designed certain reservoir outlets as headwalls on the centre lines of the dams (Fig. 20, p. 183), and believed that, when ordinary precautions were taken for uniting the masonry and earthwork by long staunching walls with cross walls, rather than by forming wing walls, this design was superior to all others on account of its accessibility. Further, it allowed of large sluices being used to keep the reservoir low during the monsoon, and thus tended to diminish its rate of silting up, and brought the flood-absorptive power of the reservoir earlier into play. Mr. Strange.

Correspondence.

Mr. J. R. Bell remarked that, although it was many years since he served in its Irrigation Branch, he would say that the Public Works Department would derive much gratification from the reception of the Paper by the Institution. From the point of view of famine prevention, both railways and canals had done much to alleviate distress; indeed, the local famines which wrought such terrible evils so late as 1867 and even later, had already been minimised, and owing to the progress made in both developments, it was only when dearth pervaded several parts of the entire peninsula simultaneously, that it was in these days heard of at Mr. Bell.

Mr. Bell. home. Happily the famine of 1897 seemed to be at an end. It might be interesting to mention that Mr. Joyner, the Superintending Engineer for Irrigation for that section of the Bombay Presidency in which the Author seemed to have spent his service to so much advantage, had been decorated by the Government of India for his famine service and specially thanked by that of Bombay for the promptness with which he prepared projects for large works when a concentration of labourers became urgently necessary in the hill talukas of Poona and Satara, owing to the reluctance of the distressed people to go to a distance. To so employ them on works which might serve to avoid future local scarcity in places where railways were never likely to penetrate was the object in view; and although it could not be supposed that, in that time of stress, all the more advanced refinements of design to which the Paper drew attention had been adopted, it was surely a good thing if this appeal for guidance succeeded in strengthening the hands of those who sought to combine progress with soundness in a peculiarly difficult branch of professional practice. Many points of design referred to in the Paper were not yet reduced to practice, while others, like the elsewhere well-known method of closure by level stages, seem to be moot points in Bombay. Mr. Bell was very far, and so he felt sure was Sir Alexander Binnie, from hinting at any serious disagreement between those who, like Mr. Joyner and the Local Government, had to decide, and any ardent junior "progressive" who, like perhaps the Author, had suggestions to offer. Such works were for the most part remote from railways and from even such skilled labour (other than that of the nomadic tribes of stone-quarriers and earth-diggers known throughout the Deccán as wuddars) as was found in the towns. The only possible building materials were those so clearly described in the Paper:—(1) Basaltic stone, with its conchoidal beds and its often treacherous liability to perish between wind and water, (2) disintegrated trap, ranging from hard "murum" to "black-cotton soil" through a whole gamut akin to the range of shales, clay shales, and clays, (3) nodular limestone or "kankar," and (4) river sand (the two last scattered and in very moderate quantities, but the two former unlimited), form the entirety of the indigenous resources of these districts. There was no timber bigger or better than firewood, no fuel but that and charcoal. Staging was commonly built, if its use could not be avoided, with Moulmein teak or with Oregon pine, railed hundreds of miles from Bombay and then carted scores of miles uphill to such works as these. Ironwork was either imported from

home or made up in Bombay, where the leading firms did excellent work at very reasonable prices when not hampered by plague or strikes. These local peculiarities might help to explain why certain devices were adopted, less from choice than necessity, and might serve to show the especial sense in which the Bombay Irrigation Department was adapting the resources of Nature to the use of man. When all was done these great reservoirs could never profess to compete with the quasi-perennial canals in the plains. There must be many such canals that delivered between 200 million and 300 million cubic feet of water to the land in each 24 hours, discharges that would empty any one of these reservoirs in a fortnight, reservoirs that were intended to hold out for two years, both against irrigation and evaporation. The latter loss must amount to several vertical feet in the year, and especially in a year of drought and hot winds. In some of the very shallow tanks of the Madras Presidency, Mr. Bell had known the hot winds to lick up, in conjunction with moderate leakage, ½ inch in 24 hours, but it might be hoped that this was an exceedingly abnormal experience. The leakage from such reservoirs as those in the Paper could hardly be called a loss, it was at most a modest form of compensation. In no case, however, could reservoir irrigation compare favourably on commercial grounds with canal irrigation. If Government must feed agricultural labourers to keep them from starving, it must exact a labour test of some kind, and labour that might avoid any future need of so feeding them at all was certainly the best way to treat what was, in any case, a bad job. The Western Deccán rainfall did not lend itself to making many "tanks," as the shallow embanked reservoirs common in Madras were called, nor to the still more elementary native system of Orissa, where each field was its own tank, and retained its own rainfall, till some evaporated and the rest was absorbed, in those fortunate seasons, when the rainfall filled the bunded enclosures, without breaching them in series. The Madras village tank was a compromise between such bunded-field and the reservoirs under discussion; the bulk of the tank-water was led to the fields below by open ducts, and would usually irrigate from two to three times the tank's own maximum area. As the water got drawn off and evaporated, the villagers followed it up, or rather down, with cultivation in the tank-bed, thus utilising at once the silt's fertility and the water of absorption, so that, in all, a shallow tank would serve to cultivate three to four times its area in normal seasons of moderate rainfall. In such districts, the bund of a village tank Mr. Bell.

Mr. Bell. was seldom higher in all than the bare freeboard which the Author's works demand, firstly, for an adequate depth of escape over the waste-weir, and secondly, for the waves which, in such mountain gorges (for the Western Ghats would be deemed veritable mountains in Great Britain), were suited to the Author's purpose. There were both waste-weirs and waves in village tanks, but the experience of centuries had led to the abandonment of sites where either difficulty had caused repeated disaster, and, in practice, the roughest-looking appliances sufficed to reduce the disastrous breaching in series of long chains of village tanks (mentioned by Sir Guilford Molesworth) to perhaps once in 50 years in any given valley of any large extent. The waste-weir or "calingula" of the village tank was exceedingly simple and ingenious. It was a substantial masonry weir with wing-walls across, where available, a rock-bedded outfall, and a number of stone posts, pitched about 2 feet apart, protrude a yard or more from the weir-crest. These dam-posts served as stanchions to uphold a wall of raw clay, which the cultivators built up in time for it to be staunch and sun-dried ere the rains top the masonry. If the latter rainfall came on gradually and unaccompanied by violent squalls, the depth of the dam-stones can thus be saved for irrigation purposes. If, on the contrary, the clay was overtopped, it washed away in no time and put the masonry weir in action. Accidents, with this arrangement, have occurred through the villagers trying to save a second supply of top-water after the temporary clay dam had been washed away early in the season. In that case, being unable to staunch the flowing calingula with clay, they had recourse to wattling or dam-boards, and thus risk the tank itself, on the chance of no second storm overtaking them at unawares. They were not alone in accepting a remote risk in the expectation of a substantial gain. And they were far from alone among the natives of India in trusting too much to blind chance and then blaming their gods or their rulers for the consequences of their own apathy. That was why he viewed the elaborate and ingenious device of a stepped-weir with no small misgiving. He regretted that he had not made himself acquainted with the details of Mr. Reinold's automatic shutter, which was seemingly put in action by filling its counterpoise chamber on emergency, but it was well to recognise that whatever of ingenuity and strenuous effort was proper for the work of an engineer in India, should be put into the business of construction while the whole was under the master's own eye, and not left to be exercised by others, and especially by natives in the course of

maintenance. Suppose, one should say to oneself, that this work were left to subordinates or to the village elders to work, the question would then arise—not so much whether it could be worked properly, as, could ignorance or carelessness wreck it when its *modus operandi* had become a vague tradition? These dams were not like a railway, where fairly competent inspection proceeded almost continuously day and night. They were not even like the large canal headworks in the plains, which each employed a resident engineering staff. Without going so far as to disapprove of the Author's design for the proposed Málávedi weirs, and while admitting the saving virtue of applying a "breaching-section" (p. 161) where feasible, it was right to say that extreme caution should be used in adopting elaborate expedients for these escapes. It might be necessary, in any case (p. 179), to maintain a special establishment at one time of year, and there was little doubt that, for a time, and perhaps a long time, the automatic gates "can be made to act," the teak crest could be removed, and the under-sluices called into play with promptitude and success; but it might yet prove that, among such people, and in such places, simpler expedients would better stand the test of time, which was the true test of such engineering as exotic rulers like the British should attempt. In some ways the Author went beyond Mr. Bell, in his desire for a permanence that might minimize maintenance, and perhaps too far in proposing a continuous concrete revetment to overlay such a treacherous material as black-cotton soil, with its admittedly serious internal strains. He would leave the details of the proposed compound dam to specialists, merely mentioning that his own Deccáni experience did not lead him to expect that much of the trap rubble would disclose natural beds suitable for being laid normal to the slope or to any defined plane. The proposed front toe was, it would appear, a solid wall built in mud mortar, made of "clayey murum," and, if so, it might be suggested that it would be better to have the puddle-trench set under the rear part of this toe. It was not clear how far either of the analogies derived from Nature applied to the section of slope proper for such works as these. Fujiyama had a parabolic slope flattening towards the base, but it probably consisted of lava and pumice and might owe its lower flatness to the drifting of volcanic ashes in the wind and rainwash. All slips had the well-known ogee slope, but that was clearly attributable to dynamic effects where a semi-plastic mass slid on a lubricated slip-plane. The section of such slip-planes themselves was analogous to that of Fujiyama, but that profile did not prevent a fresh slip from starting so soon as the counterpoising weight of Mr. Bell.

Mr. Bell. the former slip's "nose" was reduced by erosion or denudation. The proposed flattening slopes followed the Fujiyama type and the old benched-slope was undoubtedly a rectilinear adaptation of the ogee of a natural slip. He had not heard of any serious attempt to cure a slip by adding more loading to its nose. Draining the lubricating slurry of the slide was the recognised panacea, but it seemed worth while to try overloading in cases where thorough drainage of the slide-surface was impracticable. If this be the first Paper yet discussed in the Institution, which had emanated from a member of the Coopers Hill recruitment of the Indian Engineering Service, Mr. Bell would venture to say that it was well worthy of that distinction. Nothing could well be more simple, ingenious, and satisfactory, as a preliminary revetment, than setting the pitching-stones with their broad, squared ends down, as described on p. 150. It was a perfect and yet simple solution of a difficult problem. He had seen so much trouble from ripples undermining pitching set face-up, that in river-training works, &c., he had ceased to employ anything but loose stone, ready to sink and disclose erosive undercutting. If the Author deferred concreting his pitching till it was well settled, and would then concrete it up in sections with free longitudinal and cross-joints, he would make a capital job of this part of his interesting and beneficent work.

Mr. Bruce. Mr. A. Fairlie Bruce considered, as regards the puddle-trench, that unless there happened to be a fault in the line of the river bed where it crossed (when concrete might be used with advantage) there did not appear to be any essential reason why this part of the trench should be differently treated from the remainder, or why if proper care be taken it should be less watertight; the leaks, which seemed to exist more or less in almost all Indian dams, were probably to some extent due to the practice, alluded to by the Author, of leaving a gap in the centre for the escape of flood-water, which was afterwards hurriedly filled. It had for long been recognised by all waterworks engineers that all junctions in puddle-trenches, whether with the ends and sides or between one part of the trench and another, should take a wedge form, all re-entrant angles or vertical faces being carefully avoided. Where a perfectly watertight stratum could not be obtained it frequently answered sufficiently well to lay a layer of good concrete about 2 feet thick in the bottom of the trench, with a feather running along its whole length to make a good joint with the puddle. Any leakage which might take place passed below the concrete without any tendency to increase; it could then

usually be collected in a well at the back of the dam, and led into the supply pipe. Whenever the concrete was used in the bottom of a trench, it should always be lowered in skips, and not thrown down or sent through a shoot, otherwise the materials separated, and the bottom layer consisted of nothing but dry stones. In the Tulsi and Vehar Lakes, in connection with the Bombay Water Works, there were one masonry and four earthen dams, all of which leaked to some extent, and had done so since their construction, without apparently doing any harm beyond the loss of water involved. If, instead of devoting care and expenditure to the formation of an elaborate system of drainage, it were expended on the construction of the dam, a better result might be obtained. If the English practice were more closely followed of only aiming at making the heart of the dam water-tight, and forming the inner half of hard material, mixing with a certain amount of small stones well consolidated, probably Indian Engineers would experience less difficulty in making dams tight, and slips so often complained of would not have taken place. He agreed with the Author in advocating a surface slope in the layers of the embankment towards the centre, though 1 in 10 seemed somewhat more than was required, and also in deprecating an excessive use of water. This was quite in accord with the best practice in England. In the Bombay dams most of the pitching had been set with the broad face uppermost, which was obviously a mistake; as, however, none were exposed to a long reach in the direction of the monsoon gales no damage had resulted. In the absence of large scaled drawings it was somewhat difficult to follow the Author in his description of what he calls a "stepped waste-weir," but it appeared to be unnecessarily complicated, which was to be avoided when it was remembered that it would have to be worked by more or less ignorant natives. They did not seem to have been tried by the Author. As regards outlet-works, many most successful culverts on the Edinburgh Reservoir and elsewhere had been carried through the dam itself. If they were built in a trench excavated in good hard material, it was as a rule preferable to building them in a tunnel where the work was more difficult to inspect. There need be no risk in carrying the culvert across the puddle-trench if it was supported on a concrete pillar having a side batter and with a good feather up the sides and over the top to stop any creep between it and the puddle. The culvert under the Tulsi dam collapsed soon after its construction 20 years ago, but beyond a trifling leak through it, no harm had been caused. The Vehar outlet pipe was originally laid

Mr. Bruce.

Mr. Bruce. in a culvert under the main dam also, but after the accident to the Tulsi culvert it was abandoned and a tunnel cut through the hill at one end. The outlet sluices (if they could be so called), at both Tulsi and Vehar Lakes were glorified examples of the native plug, described by the Author, consisting in the latter case of a plug, 4 feet in diameter, lowered by chains into pipes projecting outside the tower with one of 6 feet diameter in the centre of the tower. When one of the pipes in the tunnel burst recently, it was found impossible to close them without the aid of a diver. Designs were at present being prepared to substitute sluice valves for them. Valves worked by rods running down the inner slope of the dam were almost as objectionable as the above, as the least subsidence caused them to be bent and jam, and there was no way of repairing them short of emptying the reservoir.

Mr. Croes. Mr. J. James R. Croes considered that the underdrainage of the embankment advocated by the Author constituted a feature of very doubtful propriety which, so far as could be learned from the Paper, had not been introduced in any dams heretofore built under careful engineering supervision. The Author propounded the theory that, "up to the centre line every precaution should be taken to prevent infiltration, while beyond this point, every facility should be given to the harmless escape of such water as has penetrated so far." To accomplish this, he recommended the construction of drystone drains along the centre line of the embankment, leading out to the toe of the outer slope. In the absence of experience and evidence to the contrary, it would appear as if this mode of construction would facilitate the leakage of water through the dam, and the creation of currents, and a steady flow through the saturated up-stream half of the embankment, and the washing out of the finer particles of that bank. If such particles were carried out through the drains, the flow of water would continually increase. If they only were carried part of the way to the outfall and clogged the drains, the result would be that the water above the point of stoppage would rise and saturate the bank above and come out on the slope of the down-stream face much sooner and with more disastrous effect than if the old-fashioned method of interposing every possible obstacle to its progress through the whole of the bank had been followed. It was difficult to believe that dams of the types shown in Figs. 8 and 9 would not be safer with the drains under the lower slopes of the embankments omitted, and the security of the bank made more dependent on what had been well termed "the abhorrence of water to a right angle" than on the affording of

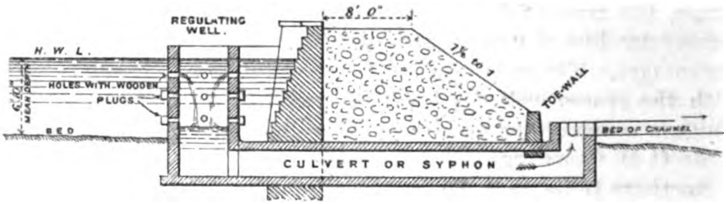
facilities to its flow. If, however, the Author's theory were correct and the water which had penetrated to the centre of an embankment had better be carried off in the quickest way, there ought to be a drain laid through the centre of the bank about 8 feet or 10 feet below the flow-line of the reservoir, and carried off to the natural surface at the ends of the dam. In an embankment not thoroughly watertight, that was the point where the danger of saturation of the outer slope causing slides was the greatest, and such a drain might lower the surface of saturation in the bank.[1] Where plenty of stone could be procured, and skilled labour was scarce, the type of dam proposed by the Author in Fig. 8, and termed by him a "compound dam," would seem to have many advantages. The construction of both of the toes of heavy rip-rap with the spaces well filled with clay would prevent the sliding which was most to be feared in such a high earthen structure. Mr. Croes.

Mr. C. H. Croudace observed, in reference to irrigation reservoirs in Northern India, that the average rainfall in Jeypore and Ajmere districts was about 24 inches, but in famine years it fell to 6 inches and less. Even in good years the rainfall was often erratic; falling on the catchment basin irregularly over small areas, which took the shape of narrow strips. Again, the rain might fall in light showers, and at other times in heavy downpours amounting to as much as 3 inches in the hour. Hence the available rainfall over a rectangular catchment basin of 5 square miles to 20 square miles had to be estimated with extreme caution, and must be based on careful rain-gauge observations throughout the basin. There were some fine old tanks built by the Rajput States prior to the British period; notably the large tanks or rather lakes at Ajmere, Odeypur, and Mandel, the dams of which consisted of a heavy facewall backed by earthwork. The surface leakage or percolation below the tank-bed and dam was found to be beneficial for the down-stream well irrigation (often for many miles), as it raised the spring level of the wells for a long distance down the drainage line on each side. Bearing this fact in view, Colonel Dixon, R.A., prior to 1857, covered the hill districts of Ajmere and Mhairwara with some hundred or more tanks or lakelets, which were of great benefit to the peasantry of the country. These dams were built in the narrow gorges of the hills of solid masonry throughout; but in the more open country or plains they consisted of earthen dams or "bunds," generally segmental in plan, *Figs. 34*, with an average height of between 15 feet to 20 feet in the centre, and Mr. Croudace.

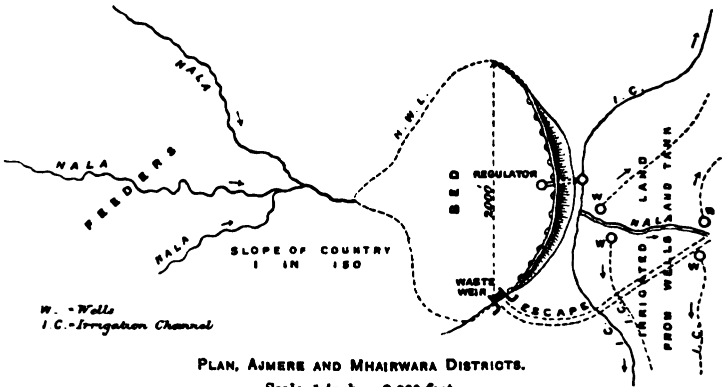
[1] Minutes of Proceedings Inst. C.E., vol. cxv. p. 158.

Mr. Croudace. varying from ¾ mile to sometimes 2 miles in length. The catchment basins varied between 1 square mile to, perhaps, 10 square miles, and the storage with an available rainfall of 4 inches would give from 8 million cubic feet up to 80 million cubic feet of water. Owing to the shallowness of many of the tanks, the net amount available for irrigation by flow was low, and their utility consisted mainly in the cultivated bed of the tank when dry and in the effect they had in raising the spring level of the wells in the

Figs. 34.



CROSS SECTION OF DAM.
Scale, 1 inch = 16 feet.



PLAN, AJMERE AND MHAIRWARA DISTRICTS.
Scale, 1 inch = 2,000 feet.

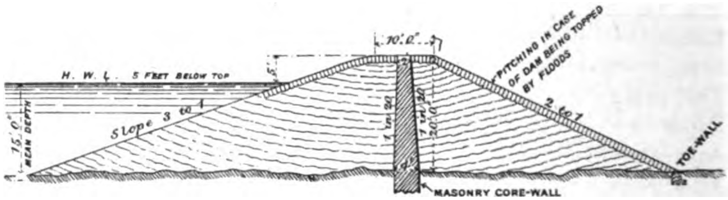
DIXON TYPE OF RESERVOIRS IN RAJPUTANA, INDIA.

rear or down-stream side of the dams, which acted as siphons in some measure. After the great famine of 1867–68, the Government of India took up on a large scale the tank irrigation of these districts under Colonel J. G. R. Forlong, Superintending Engineer, with Mr. Croudace and other engineers as his assistants. Similar work was also commenced by Lieutenant, now Colonel, S. S. Jacob, C.I.E., who since then had done so much for the economical and remunerative tank irrigation in that native state. Attempts had

been made in the Ajmere district to make Colonel Dixon's old tanks watertight by introducing core-walls of puddle or masonry, but with poor results. At the same time the repairs or maintenance was taken over by the Government from the villagers, the result being that they neglected their tanks and had no self-reliance in emergencies, such as on the breach of a dam occurring from excessive floods. Several large projects were initiated by Colonel Keatinge, V.C., Agent-Governor, notably the Bheer Reservoir (to supply Nasirabad Cantonment), and the Beawr Reservoir, on which he had been engaged, near Beawr in Mhairwara, were constructed at great cost between 1870 and 1875; but were disappointing in their results in so much that the available rainfall was far lower than estimated—due, as already mentioned, to erratic rainfall. The return on the capital outlay had not exceeded 2 per cent. to 3 per cent., and was due to heavy capital outlay on the dam and the absence of a large cultivated area immediately in rear, necessitating a great length of irrigation channels before reaching a suitable soil for irrigation. Besides, in years of drought the tanks were nearly empty, and no revenue would be secured. Within the last ten years the increase of a pure water supply for Ajmere city had to be studied, and good results had been obtained by Mr. D. Joscelyne, Executive Engineer and his successor, Mr. Foy, by damming up the gorges in the adjacent hills. The most satisfactory results, however, had been secured by Colonel S. S. Jacob, C.I.E., State Engineer for the Jeypore State for the last thirty years, who had made a special study of economical tank irrigation. He had covered the district with numerous tanks, following the example of Colonel Dixon (Superintendent of Ajmere and Mhairwara between 1847 and 1857), but on a larger and bolder scale. The most notable work was the Anasagur dam, west of Jeypore city, which crossed the very deep nala with high banks flowing from the Jeypore hills to the north. It was about 1,500 feet long by 60 feet to 70 feet high, with a water slope of about 4 to 1, and consisted entirely of light sandy soil, with a 20-feet roadway on top, and was situated up-stream of the great masonry dam, now in ruins, built by the Rajah of Jeypore about 1865, and which failed when full, owing partly to the water escaping behind the vertical sandy cliffs on which the ends abutted. Colonel Jacob, profiting by this failure, built his dam of the same material as the soil at site, and the ends of the dam were well bonded into the cliffs on each side, and thus any creep of the water around the wings has been stopped. No core-wall or puddle was used in this work. Colonel Jacob was now engaged Mr. Crouduce.

Mr. Croudace. on the huge earthen dam and reservoir across the gorge of the Ramgunga nala, where it issues from the hills on the east side of Jeypore, which, when finished, would irrigate some hundred square miles of country. The net revenue derived from his tanks throughout the district varied between 7 per cent. and 12 per cent. on the capital outlay, and the irrigation was entirely under native management. As a rule he built a masonry core-wall, *Fig.* 35, in centre of the dam, with flat water slope, and the down slope was well pitched with stone to avoid damage in the rare case of the dam being topped by flood waters. The waste-weir where practicable was cut out of the solid rock. The rates for work were very low in this district, masonry being built for Rs.15 per hundred cubic feet, say 5*s.* per cubic yard, and earthworks at 1½*d.* to 2*d.* per cubic yard. It should be noted that excessive evaporation coupled with percolation of the storage site would mar

Fig. 35.



Scale, 1 inch = 32 feet.

JACOB TYPE OF DAM, JEYPORE STATE.

many a promising project, and that the site of a reservoir had to be carefully surveyed and contoured before fixing on the position of the dam, which again must be considered with reference to suitable soil for cultivation below the site of dam. Careful experiments on evaporation had been made long ago by Mr. Culcheth, M. Inst. C.E., and Mr. D. Joscelyne, both for a long time Executive Engineers in the Ajmere district, the records of which were buried in Government reports and files. Reservoirs for railways were also of great importance in Rajputana, as the ordinary station wells in many cases contained brackish water, causing great interference to the working of any large traffic. One of the finest reservoir sites in Rajputana was to be found in the desert district of Bikanir, where a catchment basin of some 40 square miles consisted of sheet rock, the flow-off of which passed through a narrow gorge about 100 feet wide. This high level site he had utilized for the Delhi-Karachi (direct) Railway project of 1889–90, for sup-

plying the line with water by gravity through pipes for some 200 miles through the sand hills or "tiba" district. The reservoir was estimated to hold a 5-years' supply, amounting to 70 million cubic feet of water. It was to be built of masonry from 60 feet to 70 feet high, and roofed over with a view of reducing the loss by evaporation. The Bikanir State attempted to dam this stream with a huge masonry wall built of ashlar blocks (set dry) with an earth backing; but it was destroyed by the first flood, and cost this poor desert state a large sum of money. The estimated cost of this covered reservoir of 70 million cubic feet was £233,333 (exchange at 16*d.* per rupee), or at the rate of 1*s.* 9½*d.* per cubic yard of water stored. Mr. Croudace.

Mr. G. O. W. Dunn was entirely in accord with the general principles advocated in the Paper. The subject had engaged the attention of irrigation engineers in Western India for many years past, and the Author had embodied in his Paper, with certain additions and suggestions based on his own practice and observation, the general conclusions which had been arrived at by the Bombay Public Works Department as the result of upwards of twenty years' experience in the construction of earthen dams. The application of the main principles brought forward in the Paper was not confined to India, and to Colonial Engineers especially the Author's remarks should prove of very great value. As a young assistant he had had charge for some time of one of the works mentioned by the Author—the Nehr dam in the Satára district—on which a large number of famine relief labourers were employed in 1876–77. The closure of that dam, however, was done after his transfer elsewhere. He was also connected for a time with the Author on the repair of the Waghad dam, the failures of which (for there were two) had been most instructive, and afforded an example of the saying that there was often more to be learnt from failure than from success; and, in addition, he knew personally all but one of the others of the ten completed works of which details were given in Appendix I., the works numbered 11 and 12 being projected only, and hitherto condemned by the supreme Government. Five of the ten completed dams mentioned had given trouble, owing to slips. Four of these were the first four in point of maximum height, and the fifth was the Ashti dam, the slip of which was, he believed, mainly due to the nature of the foundation, which was of "karal," a soil described by the Author on p. 140 under the head of "foundations." There was no doubt that the material adopted for all these dams, viz., the most retentive "black soil" available, and the system pursued in those Mr. Dunn.

Mr. Dunn. days (for all were constructed many years ago) of very copious watering to each layer, were the chief causes of failure, though in the case of the Waghad dam a great mistake was made in ever attempting an earthen dam at the site, which was eminently suitable for a masonry dam with earthen flanks. The dams which had stood well were: (1) those of moderate height on good foundation, and (2) those which, for want of "black soil," had of necessity to be constructed of lighter soils, less retentive of moisture, as brown, red, or whitish soils. None of the ten dams were drained in construction, and those made of "black soil" and founded on the same, or on "karal," and without any natural drainage in the subsoil, became, with their foundations, like over-wet dough and sank with their own weight, bulging out at the toe on the down-stream side, but kept from doing so on the up-stream side by the superincumbent weight of water. The necessity of providing for the efficient drainage of such works was established beyond question, but he observed that the Author still advocated the use of "black soil," modified, however, by admixture with half its bulk of "murum," or other dry material. He much preferred to reject this rich and exceedingly retentive soil altogether, save only where its use was absolutely necessitated by the absence of other soil within reasonable distance, for experience had shown that a brown soil, or red laterite washdown, or the light-coloured soil locally known as "mán" earth, made an infinitely more satisfactory dam in every way. If "black soil" had to be used it should be mixed with finely broken "murum," when in as dry and powdery a condition as possible, water being added to each layer after consolidation to the absolutely necessary extent only. He agreed with the Author's objections to the use of two trenches, one of puddle and one of concrete, across the river bed, but in recent examples he believed he was correct in saying that this system had not been followed, one central trench only being adopted, the portion across the river bed being filled with concrete and well keyed into the puddle at either bank. He did not think a properly drained dam required the use of berms. The Author acknowledges that the material would be more effectually used to give a flatter rear slope to the dam, and he said that the chief advantage of a berm was to weight the surface of a dam and prevent it bulging, but if made with a sufficient slope and properly drained the dam ought not to bulge, and the sight of a berm on a dam would lead him to the conclusion that the original construction was so faulty that it had been found necessary to weight the toe in this manner. Drains on the face of a dam

were most dangerous, and should be altogether avoided. As regards the closure of reservoir embankments, he agreed with the objections put forward to what was described as the "ordinary system," and considered the "new method" to be very decidedly preferable where the conditions admitted. It seemed to be assumed, however, that the bed of the stream to be dammed up was dry, or, at least, carried but an insignificant trickle of water for the seven working months, and this, no doubt, was generally the case in Deccán practice. Were there any constant volume of water to be dealt with, a culvert through the bottom of the dam or through the bank would appear to be necessary in order to enable the dam to be raised safely above the level of the first temporary waste-weir, when the culvert could be permanently closed. The Author's "compound dam" was not likely to be generally adopted in preference to the ordinary type on the score of its additional expense. It was stated in the Paper that "this form of compound dam is only economically feasible where durable stone can be obtained cheaply and abundantly. This is likely to be the case at the sites of gorges which imply the existence of hard materials, and it is for such sites that the type is best suited." When, however, a rocky gorge, where durable stone could be abundantly and cheaply procured, was to be closed, a masonry dam was obviously the proper form to adopt, while for ordinary sites and for dams up to 60 feet or even 70 feet the usual type of earthen dam, with the precautions as to drainage and methods of construction noted in the Paper, was entirely suitable. For greater heights it was probable that the additional cost of a masonry dam would be repaid by the extra security afforded, and by reduced expenditure on maintenance. Mr. Dunn.

The Author had incidentally mentioned the suitability of large earthen dams as works for the employment of famine labour, and though this question was distinct from the subject of the Paper under discussion, it was one of great interest to the Indian engineer. It might be at once conceded that a large earthen embankment was in itself an ideal famine work. It could afford employment to large numbers of unskilled labourers, men, women, and children, at one place. Being so concentrated, supervision was easy and economical. The labourers could be hutted in properly laid out camps on selected sites in the immediate neighbourhood, and the sanitation and water-supply could be under constant observation. Hospitals and relief kitchens could be established in connection with the work, and satisfactory arrangements made for the necessary supplies of food. Were the object

Mr Dunn. merely to give relief without pauperising the recipients, nothing could be simpler than to raise these enormous heaps of earthwork at convenient centres. But the true policy of famine relief was to employ the labour as far as possible on work that would be of ultimate benefit to the country, either by affording some security against deficient rainfall, or by so improving the means of communication that the effects of a scarcity were reduced to a minimum, or again by reducing recurring charges on existing works for some years to come—as for instance by the collection of stocks of stone metal for road repairs or for railway ballast. The construction of large irrigation works was very frequently urged as the great defence against famine and as the class of work on which famine labour should be mainly employed. Railway earthworks were excellent for the purpose, but it was no use making railways where there was no prospect of even paying working expenses. Roads were useful and fairly suitable works, though they involved the spreading of the labour over long lengths, making efficient supervision difficult and expensive. But a road when made had to be maintained, and if the traffic was only likely to be small the result was an unnecessary burden on the Local Board or on provincial resources. In the case of irrigation works regard must be had to the conditions obtaining, and, as far as Western India was concerned, experience so far had shown that the construction of storage reservoirs, though affording the best possible work for the employment of famine labour, was the most extravagant form possible. In the famine of 1876–77, when there was a "boom" in irrigation in the Deccán, a very large portion of the relief labour was employed on earthen dams for storage reservoirs, and when the famine that had just closed was threatening, he had occasion to take out some figures relative to those works. He found that for every rupee spent on them during the famine, two rupees had to be spent afterwards to complete the works and bring them into operation, and that the result after all had been a considerable nett annual loss to the Government. The cause for this was not far to seek. That considerable expenditure was necessary over and above the earthwork of the dam was obvious, and that annual charges for establishment and maintenance would be involved was of course foreseen. Where the failure had been was in the small advantage that was taken of the means of irrigation provided, and in the fact that when the water was wanted most, owing to failure of rain, it was not to be had. A closer study of the circumstances should have convinced the projectors of these works that this must be so. It was stated at the commencement of the Paper that (in Western

India) irrigation reservoirs might be divided into two classes, (*a*) 'Ghaut-fed,' with an assured annual replenishment, and (*b*) Eastern, with an uncertain annual replenishment. In the Western districts, with the assured annual rainfall, there was no necessity for irrigation or for relief works. Where they were required was in the Eastern districts—in what was known as the "famine zone"—where the rainfall was capricious. As the reservoirs, equally with the crops, depended upon the rainfall, the supply to them was deficient just when the crops most required them. Again, the volcanic formation of the Deccán was very different from the alluvial plains of the Punjab and Northern India. There were no large perennial rivers fed from Himalayan snows and charged with fertilizing silt. The Deccán watercourse, or "nullah," was a roaring torrent after heavy rain, but was dry, or nearly so, for the greater part of the year. The country was a succession of barren ridges and of valleys, which were, as a rule, very rich and fertile. The black soil, of which these valleys are chiefly composed, wanted only moderate rain to produce luxuriant crops, and sufficient was generally forthcoming. There was, therefore, no inducement to irrigate anything but garden crops which required a good deal of capital, for the land must be levelled and the clear reservoir water necessitated heavy manuring. Those farmers who could afford to grow such crops were not those who suffered when a scarcity occurred. It was the vast numbers of the poorer occupiers, the labourers, and the artizans who had to be cared for; and, as far as they were concerned, the existence of the Deccán reservoirs had no appreciable effect. It would thus be understood that, excellent as such works were in themselves for the employment of famine relief labourers, the construction of earthen dams for irrigation reservoirs was not likely to be undertaken for the purpose, save in exceptionally favourable cases, until all other useful and suitable classes of work were exhausted; and then it was highly probable that, on the cessation of relief measures, the unfinished heaps of earth would be allowed to remain untouched until the next similar calamity afforded an opportunity of going on with them. The whole question of the suitable employment of relief labourers was extremely difficult, and his remarks might be regarded as an answer, from the particular part of India in question, to those who would advocate indiscriminately the further extension of irrigation as the great remedy for the evils of an uncertain rainfall. Mr. Dunn.

Mr. W. Fox desired to take exception to the Author's statement that engineers as a rule viewed the construction of dams Mr. Fox.

Mr. Fox. of more than 60 feet in height with distrust. There were innumerable instances of such constructions in England, and, were the limit placed at 60 feet, very many reservoirs with embankments of from 80 feet upwards, if reduced, would not be worth making, as the capacity obtained with the lower height would be so small. He had investigated two instances where he found that the difference between 60 feet and 80 feet in the height of the embankment added 100 per cent. to 150 per cent. to the capacity of the reservoir without increasing the cost in anything like the same ratio. Nor could he agree with the Author's statement that, "notwithstanding all precautions, some water would certainly pass through the puddle." Should such be discovered, it would, in his opinion, be a source of very grave anxiety. No doubt it was not uncommon for water to pass round the ends of the puddle-trench or underneath, if the foundation rock was stratified; but so long as the water issuing was clear it was of no consequence; and his experience was that such leakages gradually decreased. He considered it unnecessary to make the puddle-trench as wide as 14 feet; and with regard to the suggestion by the Author that a longitudinal dry-stone drain 4 feet by 3 feet should be placed in the bottom of the trench, he would draw attention to the unnecessary width of trench caused thereby. Moreover, he thought the very last place for laying a drain should be along the bottom of the puddle-trench, although at times it was necessary to bring up vertical stand-pipes to relieve the trench of any springs which might be found, and he had on one or two occasions surrounded the bottom of the stand-pipe with a small quantity of dry rubble stone. Round this, however, he invariably placed the very best concrete that could be made. He sometimes continued these vertical pipes to the drain underneath the outer part of the embankment; but if the water should cease to rise in them below the surface of the ground he filled them with cement grout and left them. With regard to the proper slopes to be adopted, he considered that no hard-and-fast rule could be laid down, although he considered the suggestion shown on Fig. 8—viz., to flatten the slopes as the height increased—a good one. Everything, however, must depend upon the material at hand. With dry stony material, he had constructed an embankment, with an outer slope of 2 to 1, nearly 100 feet in height with perfect success. On the other hand, with rich clay he had found it impossible to get this slope to stand even at 20 feet to 25 feet. With such material, he had successfully adopted the suggestion shown on Fig. 8, of constructing the inner

and outer toes of dry stone or burnt ballast, the latter having been Mr. Fox. used where a large quantity of lias and oolitic silt had to be got rid of. Instead of running it to spoil, it was burned *in situ* in the toes of the embankments, and it was found that after this had become saturated with water it had set hard and become practically a mass of concrete. It so happened that in this instance a quantity of town refuse was obtainable, which took the place of small coal or breeze, and the cost of the work was much less than it would have been had the material been run to spoil and the toes made with dry rubble. The question of a proper amount of moisture to be used in the formation of an embankment in England he had never heard fully discussed. In his own opinion, although he had recently known as much as 4 inches of rainfall in twenty-four hours, which rendered an embankment in progress so wet that work could not be resumed for some days, he believed that, so long as it did not cause the slopes to slip, it was impossible to use too much water, as it helped consolidation. And in the preparation of the puddle, it was his practice to use much more water than was apparently used in Western India, for it would be impossible in any puddle-trench or puddle-wall which he had constructed to put a heavy roller upon it. He also doubted the advisability of rolling each layer, as it had a tendency to form horizontal planes corresponding to straight joints in brickwork or masonry, which facilitated the passage of water. He much preferred cutting the puddle with long grafting tools 12 inches to 16 inches in length, and afterwards treading it—by which means one layer was thoroughly incorporated and bonded into the one below it. The quantity of water used must depend upon the tenacity of the clay; but he aimed at making the puddle so soft that it would only just bear the weight of a man when treading it. He did not see the use of making the whole of the inside of the embankment impervious to water, because, however well this might be done, the material underneath the base of this part of the embankment was, at any rate in England, more or less open and porous, especially in the bed of the stream; and thus, although the embankment might be watertight, water would find its way underneath the embankment up to the puddle-trench, which must always be the key to the success of the whole structure.

Mr. David Gravell remarked that one of the most notable Mr. Gravell. differences between the construction of earthwork dams in Bombay and in the United Kingdom was as regards the use of puddle-walls, which the Author mentioned as never there occurring in

Mr. Gravell. the dams themselves, the puddle being confined to the foundation trench, as distinguished from the almost universal practice here of carrying up the puddle-wall to or near the top of the dam. To reconcile this important difference in practice, presumably the "black cotton" soil must be regarded as puddle, and therefore might be used equally well in the puddle-trench, especially as there, being confined, its tendency to slip would be of little importance. The depth of the puddle-trenches was also much less than was generally found to be necessary in England, so that the geological conditions of Bombay might be considered as more favourable for dam construction. It appeared that in Bombay it was usual to form the outlet by a culvert through the natural ground under the dam, and this being so the Author's recommendations for ensuring a solid foundation throughout the length of the culvert by a wide concrete foundation, &c., were of great importance, especially as regards the crossing of the puddle-trench and the use of concrete to the full depth of the trench in place of puddle, where the culvert crosses. The Author stated his objections to the adoption of the outlet formed by tunnelling in the hill-side clear of the dam, and although admitting that, being quite independent of the dam, it could not cause damage, on the other hand, stated that it was very expensive, and, being underground, difficult of supervision. This was the more likely to be the case in a country such as Bombay, where skilled labour of the particular kind might be difficult to obtain, but in England it was becoming generally recognised that wherever practicable this form of outlet was far preferable to the old method of culvert laid through or under the base of the dam. An instance of the early type of earthwork dam for a reservoir was the Glencorse,[1] for the Edinburgh supply, designed by Telford, and although the thickness of the puddle-wall was about twice that now adopted here in general practice, the slope of 3 to 1 on the inner side was still almost universally adhered to, but for the outer slope was steepened to 2½ to 1,[2] and in some instances 2 to 1,[3] the latter being also that of the type adopted in Western India.

Mr. Herschel. Mr. CLEMENS HERSCHEL remarked that there was probably no greater contrast than that between the methods of construction of similar engineering works in India and in the United States. In the one, native labour, not infrequently pauper labour, and

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[1] Minutes of Proceedings Inst. C.E., vol. lxxiv. p. 91.
[2] *Ibid*, vol. lxxiv. p. 91.
[3] "Engineering," Institution of Mechanical Engineers, vol. xlvi. p. 465.

Mr. Herschel.

including women and children, did the bulk of the work, by semi-civilized methods, for a few cents daily wages; in the other, native labour scorning to do any such work, but allowing sturdy male immigrants to grow rich in their own estimation in one working season, by doing it with the aid of superior labour-saving machinery. And yet the forces to be overcome were the same in the two places, and earth that would puddle in India would do the same in the United States. The difference was one of social conditions and of kinds of civilization, and if an engineer wished to achieve a maximum of success, he must always take cognizance of such differences and of the habits and abilities no less than the prejudices of the labouring people of the different countries in which he might be called upon to do work. Differences between Indian earth dams and American earth dams there would always be; but some changes in the design of Indian earth-work dams might suggest themselves to Indian engineers from the consideration of American methods. His view of the essentials of an earth-work dam was a structure, composed of an unstable watertight curtain fastened across the watertight surface of a valley, extending up to a horizontal line and held up or supported on each side by an earth fill. The slopes of the earth fill must be protected, on the one side against wave action, on both sides and on top against the destructive effects of rain. There must be a waste-way able to discharge a flood, the greatest known, or to be expected, flood, without raising the water higher than flood-level in the reservoir, and there must be a way provided to draw off the water as wanted. Before discussing how this programme was to be embodied in earth, stone and metal, he would define some of the terms he would use. Clay was sticky, treacherous and mud-producing. It encumbered the site of the works, and he had never found a use for it, except to make clay-rolls for pouring lead-joints, in an experience on hydraulic works, during the past 35 years. When present on the ground, it must be endured, but he had never allowed it to be brought to the site of the works. Gravel was a natural mixture of earth, sand and pebbles; of various attributes and consistencies; some of which was good for building earth dams, and some not. The best for that purpose was gravel that would puddle, or "binding gravel." To tell whether any given gravel would puddle, and to judge of its fitness for use in a dam, it should be mixed with water in a pail, to the consistency of moist earth about to be used in a dam, or before rolling. If, on turning the pail upside down, the gravel remained in the pail, it was fit for use; but if it dropped out,

Mr. Herschel. it should be discarded. Good gravel, or binding gravel, would make the best of coffer-dams, or filling for sand-bags to be used in coffer-dam work, and earth dams. It would remain water-tight, where clay would melt out and disappear like soap or sugar. Good earth or gravel, stone and metal parts being provided, the method he advocated for the construction of an earth dam was the following. The site should be cleared of perishable material, and a trench dug down to waterproof strata. If good rock was found within 25 feet, or 30 feet, or 35 feet, a start should be made upon it, but if not, excavation should proceed with some sort of stop-water until there was no danger of water passing out from the reservoir down the valley, in quantity underneath the bottom of the trench. This was a matter of judgment. A concrete or masonry core-wall should be constructed in this trench, say 4 feet or 5 feet thick at the bottom, 8 feet thick at the original ground level, 4 feet thick at the top. These were dimensions for first-class work; but such core-walls had been built, only 2 feet thick uniformly from top to bottom. At the same time with it should be built up the earth dam on each side of it, using for the earth dam good binding gravel, hauled on and spread in 4-inch or 6-inch horizontal layers. These should be sprinkled with a hose constantly, and rolled with grooved rollers plentifully, and until a hole dug in the gravel would hold water like a pail. The grooved rollers were made of disks of cast iron strung on an axis, the alternate disks being of the same diameter; and contiguous disks, about 2 inches smaller and larger in diameter than their neighbours. Such rollers could be turned easily, and their total weight was concentrated on an aggregate bearing surface equal to only half the length of the whole roller, and therefore more effective where it rolled than if the whole length touched the earth. The reference to these rollers on p. 147 misapprehended their function and object. Slopes of 2 on 1 were sufficient for both sides of the dam; 1½ as well as 2½ have been used. Berms were advantageous during construction, as level track-ways, from one side of the valley to the other; but their use was a matter of fancy, largely. He favoured them and had always used them for earth dams over 40 feet high. A gravel walk should be made on the top of the dam, and a vacant strip left on each side of it, to the edges of the dam. These top strips and the berms should be sown with grass. The back or down-stream slopes might be sown, or sodded, or covered with a layer about 2 feet thick, of small (8 inches or 9 inches in diameter) stone culled out of the gravel filling while building the dam. The waterside was paved. He had used with success large

Mr. Herschel.

boulders from the borrow pits with smaller boulders and small stone in the interstices. To draw off the water he had used the "dry-well" method. Near one end of the dam, a ditch was excavated at right angles to the core-wall trench, and at the elevation of the bottom of the reservoir. At the crossing of the two trenches was placed the dry-well, a square tower or chimney having one, two or more divisions in plan, and built up as the dam was built up. Culverts led to it both up-stream and downstream, and through it run two, four or more cast-iron pipes. Ordinary stop-valves were set in line of these pipes, two stop-valves "in series" in each line of pipe. One of these valves, the downstream one, was for use, the other for the event of repair of the downstream valve being necessary. The wasteway was a separate structure. Nothing but a smooth stone weir, of length sufficient to pass the maximum flood without unduly raising the reservoir water-level, seemed a safe arrangement. This type of safety-valve would not get out of order. The earth-dam was safe against the attacks of vermin; they could not penetrate the core-wall. The core-wall was a safe stop-water to rely upon, whether of masonry or concrete. It would not crack like clay-puddle. If it should crack, by faults of construction, the crack would not enlarge, should water reach it. It would be more likely to silt up. Drains under the dam were uncalled for. A dam of this kind had never indulged in such slips and slides as were portrayed in the Paper. Such slipping could only be caused by a lack of staunchness of the whole structure. Water must have penetrated the body of the dam, and have come dangerously near to carrying away the whole of it. A core-wall dam could be built in less than one summer season, and the reservoir filled with water the following winter. The main earth-dam of the Canistear Reservoir of the East Jersey Water Company of New Jersey, U.S.A., was about 57 feet high from the original surface of the ground to the top, and about 672 feet long on top. The water area of the reservoir when full was 323 acres; contents, 2,407 million United States gallons (at 231 cubic inches). The wasteway was 275 feet long, to provide for the floods, possibly, of 10·5 square miles of drainage area.

A Lidgerwood cableway was used to build the core-wall; steam pumps, two tanks, and lines of piping furnished the water for sprinkling and to the steam-driven concrete mixer; carts, and wagons, and rollers in number, to fairly crowd each other off the top of the filling, were at work while building the earth dam; steam hoisting-engines handled the derricks; and an electric light plant furnished the light for night-work. In this way, a dense

Mr. Herschel. forest, on the site of the dam on June 10th, 1896, gave place to the practically completed dam by November 1st following, that was, 5 months later, when the gates were closed, and the water was allowed to fill the reservoir. The reservoir had been full since August, 1897. He had built two such reservoirs, a masonry intake dam across the Pequannock River, three gate-houses, and a lot of bridges and culverts, by day labour, also 26 miles of steel conduit by contract, in the two working seasons of 1890 and 1891. These works had been in use since the 1st May, 1892. To build the Canistear Reservoir in 5 months cost about £9,000 more than it would have cost to build it in two seasons.

The bill of quantities of work is as follows:—

Main dam and reservoir, clearing	440 acres.
" " grubbing . . .	440 "
Excavation on dam-site	11,000 cubic yards.
Gate-house cut, rock	1,200 " "
" " earth	5,700 " "
Core-wall excavation, rock	2,450 " "
" " earth	2,100 " "
" " concrete	8,000 " "
Dam, earth, including paving	98,000 " "
Gate-house masonry, brick	100 " "
" " stone	1,500 " "
" " concrete	150 " "
" fittings, pipes, valves, stairway, &c. . . .	
New road	11,562 feet.
Overflow dam, excavation, earth	2,700 cubic yards.
" " rock	1,450 " "
Masonry	4,500 " "

Auxiliary Dam No. 1.

Clearing site of dam	850 " "
Excavation for core-wall, rock	80 " "
" " earth	150 " "
Core-wall, concrete	300 " "
Earth dam, including paving	1,400 " "

Auxiliary Dam No. 2.

Clearing site of dam	950 " "
Excavation for core-wall, rock	20 " "
" " earth	600 " "
Core-wall, concrete	750 " "
Earth dam, including paving	2,450 " "

Mr. Hopkinson. Mr. John Hopkinson remarked that, in England, where the average rainfall of the wettest month in the year did not exceed

twice the average of the driest, the difficulties to be contended with in collecting, storing, and distributing water in India, whether for irrigation or for the supply of towns, could scarcely be appreciated. A general statement was given in the Paper as to which months in the year, in the Bombay Presidency, had a heavy and which had a small rainfall or none at all, and also a few instances of heavy falls of rain in short periods, a day or less, but the average monthly fall at Bombay, and the extreme deviations from the average, might also be of interest. The monthly rainfall at various places in the British Empire had been given in a series of Tables in "The Colonies" and "The Colonies and India," from 1874 to 1881, and from that date onwards in "Symons' Monthly Meteorological Magazine," the record for the 23 years, 1874 to 1896, being complete. The means for this period showed that the months of heaviest rainfall at Bombay were June to September, not July to October, as stated by the Author to be the case generally in the Bombay Presidency. The mean monthly fall for the 23 years was as follows, the year being purposely divided into three periods of four months each, commencing with February. Mr. Hopkinson.

—	Inches.	Days.	—	Inches.	Days.	—	Inches.	Days.
February	0·04	0	June	20·12	21	October	2·29	5
March	0·02	0	July	26·36	29	November	0·49	2
April	0·01	0	August	14·24	27	December	0·06	0
May	0·63	2	September	11·67	20	January	0·13	1
	0·70	2		72·39	97		2·97	8

Of the mean annual rainfall of 76·06 inches on 107 days, less than 5 per cent. thus fell on only 10 days in the 8 months October to May, and more than 95 per cent. on 97 days in the 4 months June to September.

The maximum monthly falls were:—

—	Inches.	Days.	—	Inches.	Days.	—	Inches.	Days.
February	0·51	3	June	43·45	28	October	10·40	13
March	0·21	3	July	47·64	31	November	2·63	7
April	0·08	2	August	36·56	31	December	1·14	3
May	6·30	9	September	22·80	26	January	1·85	4

Mr. Hopkinson. The minimum monthly falls were:—

—	Inches.	Days.	—	Inches.	Days.	—	Inches.	Days.
February .	0·00	0	June . .	5·11	14	October .	0·00	0
March . .	0·00	0	July . .	10·75	25	November.	0·00	0
April . .	0·00	0	August .	4·08	19	December .	0·00	0
May . .	0·00	0	September	1·62	9	January .	0·00	0

While 8 months in the year had been absolutely rainless, rain fell every day in July in 6 years out of the 23 years, and every day in August in 3 years. In questions relating to water-supply and storage, it is perhaps of most importance to note the wettest and driest periods, especially the latter. The wettest period was from June to September, 1878, when 105·05 inches fell, being 26¼ inches per month for 4 months; the next was from June to September, 1896, when 96·47 inches fell, 79·34 inches of this amount falling in June and July; and the next was from June to September, 1874, when 82·11 inches fell. Provision should therefore be made in Bombay to dispose of a fall of at least 100 inches in 4 months, and of 80 inches in 2 months, and in some places in the Presidency the fall doubtless greatly exceeded these amounts. The longest period without any rain was between October, 1875, and April, 1876, while only 0·01 inch fell in May, on 1 day, so that, practically, there had been 8 consecutive months without rain; there was no rain from November, 1891, to April, 1892, inclusive; and twice there had been only 0·01 inch in these 6 months. Thus it was necessary to have sufficient storage-capacity for an 8-months' supply, while it should be anticipated that a 6-months' supply might frequently be required. With regard to variation in the annual rainfall, there was not nearly so much falling off in the driest year as there was an excessive fall in the wettest; the smallest fall in any year was 57·82 inches in 1888, and the greatest, 111·93 inches in 1878.

Mr. Hutton. Mr. W. R. Hutton thought the methods of the Author were sound, and showed great care and intelligence in the construction of his works. Some of his details seemed unnecessary, and in a few points undesirable or dangerous. Methods of construction of earthen dams were largely matters of the materials at hand. There had been recently, however, much discussion upon materials and much difference of opinion. All the clays come from the decomposition of the feldspathic or other crystalline rocks. The

purest, kaolin, was composed of alumina, silica, and water, and the smaller the proportion of silica the more water would it absorb and retain. Common clays were composed of finely-powdered feldspar, quartz, and other minerals, and often more or less kaolinite. They always contained sand or other impurities. The materials, therefore, which were classed as clays differed greatly in character. Some of them were utterly unfit for hydraulic works; some were so soft as to be called quicksands. To this variation of character might be attributed the various opinions upon the value of clay in embankments. The same might be said of the gravels or gravelly earths. Those which contained no binding material were not suitable for embankments to hold water. Mixed with clay in suitable proportions good results were obtained. It would seem from the description that the black cotton soil, watertight, could be made a very suitable material for reservoir banks by the admixture of a considerable proportion of murum, which was decomposed trap, heavy, hard, and friable. It would doubtless prevent cracking and slips, which were the consequences of using the cotton soil unmixed. The puddle trench and the puddle wall of the older American engineers, which had done most satisfactory work, had been to a great extent superseded in the northern parts of the United States by the core-wall of concrete or other masonry, and the soft puddle formerly used was replaced by a material made with much less water that it might be compacted by means of the grooved roller. Doubtless the soft material would settle more than the drier mass, and as it settled would pack more solidly into the sloped sides of the trench. The puddle wall was continued through the embankment to high-water line. It was the chief dependence to prevent percolation. The core-wall of later days was intended to take its place. It was carried down to an impermeable stratum, and was built with a batter in the centre of the bank to near its top. To be of use the core-wall must be thoroughly well built. It was his own practice, where a core-wall was used, to plaster smooth the battered sides and place against them a certain thickness of soft puddle, which in settling was packed firmly against the wall. The same method was followed wherever embankment was in contact with masonry. The latter was built with a smooth batter, and soft puddle was interposed between it and the rest of the embankment. This method had been in use for 50 years on the Chesapeake and Ohio Canal with the best results. It was recommended by Graeff in his memoir on the canal from the Marne to the Rhine, and had been found uniformly

Mr. Hutton.

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Mr. Hutton. successful in his practice. The Author attached, perhaps, too much importance to the filtration through and under the bank. If the front part of the bank was made of good material, well connected with the solid ground on which it rested, but little water could pass the puddle wall or the core-wall, and that little was absorbed by the material of the outer slope. Every effort should be made to prevent filtration, which, little by little, would carry away the material from the outer slope, cause slips, and, if neglected, more serious damage. Cases had occurred in which a spring had been discovered after the base of the embankment had been prepared. When this occurred it must be carefully covered, and the water carried off by a drain, but it was always a source of danger. On the other hand, embankments to hold water were sometimes built from necessity of a material which could not be made watertight. In such case the heavy puddle or core-wall aided by puddle was depended on to stop the water, the slopes being merely the supporters of the stop-water; but if the subsoil water or water from the reservoir escaped through seams in the underlying rock, it did no harm to the reservoir, and was, moreover, very difficult to prevent. The small trenches shown on *Fig. 9* are useful to prevent filtration between the natural earth and the embankment. They might be continued at the ends, but a single puddle trench carried well into the hill and carefully filled should be ample to prevent filtrations. The ground sloping transversely to the axis of the dam was always cut into horizontal benches with, not vertical, but sloping faces. Slopes in the direction of the axis were better left alone. The earth rarely slipped upon the natural surface; if it did it consolidated the bank. Formerly the earth was spread in 6-inch layers and consolidated by the carts. The grooved roller now did the work with greater efficiency. The water-slope of the dam was protected by "pitching" rarely less than 12 inches deep, laid upon 6 inches of gravel. The latter was an effective protection against any "vermin" found in America. The more frequent practice was to lay this work in cement. The closure of a dam or a stream whose discharge was greater than could be carried off through a practicable culvert or bye-pass must be made with masonry, which would probably be used as the waste weir. The outlet culvert could be made perfectly safe by good workmanship, ample material, and numerous cross walls around it to prevent water following its straight lines; the circular form was preferred. No objection could be made to cast-iron pipes if bedded in and covered with good concrete, with cross walls at intervals over and around the concrete as in the culvert.

The valve-tower was placed at the foot of the water-slope. In one case an iron pipe 4 feet in diameter to which the gate was attached was built into the wall. The pipe was continued a short distance under the embankment, and was joined to the 6-foot culvert by a cone of brickwork. For ordinary purposes a sliding gate was sufficient; where the opening was large and the head considerable, the form of gate proposed by Mr. Fontaine, Engineer of Ponts et Chaussées, was to be preferred.[1] Mr. Hutton.

In his conclusion the Author again referred to the drainage of the embankment, taking every precaution to prevent filtration up to the centre line, while beyond it every facility should be afforded for the escape of the water. If there were a puddle wall or a core-wall the motive would be apparent, but he did not see why an arbitrary line should be drawn at the centre of the bank up to which it should be made as tight as possible. Why should it not be drawn at the foot of the outer slopes?

Mr. F. KREUTER, of Munich, thought that, in view of the dreadful disasters which, as a rule, arose from the failures of reservoir dams, safety was the factor of primary importance. High dams should, therefore, not be constructed where the ground was of a treacherous description. When, however, a water-proof stratum could be reached by the trench, then the core-wall or hearting should be made thus as to join best with that stratum. According to a well-known rule, therefore, masonry or concrete cores were recommended, when the impervious strata were rock, and puddle-cores when it was clay. The measures to be taken in favour of safety should be improved as the height of the dam was increased. Since, however, the volume of the dam grew at a very high rate with its height, the additional expenses for more perfect precautions would be found to be relatively small in proportion to the volume. He agreed with the Author that, "It is better to prevent slips at some extreme outlay than to run the risk for the sake of a comparatively small original economy." He was somewhat diffident of the safety of high earthen dams constructed after Indian practice. The Author himself stated, on p. 166, that "Although Indian dams are carefully constructed, still slips occur." It would, therefore, seem that, for high earthen dams only a system of construction, similar to those peculiar to England and America, should be used. The Author apprehended that unfavourable internal stresses might arise from the use of different materials. He thought it would be, on the contrary, advantageous Mr. Kreuter.

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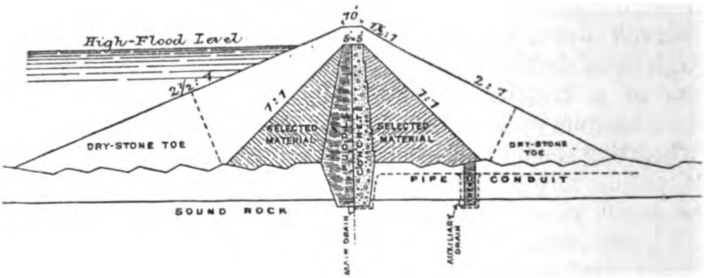
[1] Annales des Ponts et Chaussées, 1886, vol. xii. p. 254, plates 32, 33.

Mr. Kreuter. to compose the dam of certain portions, each of which had to serve for a definite purpose, provided that every portion was so arranged as to be allowed to settle without injuring the others or getting in disorder itself. The large plane-joints in which those portions abutted against each other, and which broke the layers in which the several portions had been built, seemed to be favourable to impermeability. This latter important quality was, as experience taught, never attained by the more or less perfectly stratified structure of Indian dams, and the danger of being percolated and soaked increased with the head of water. He would, therefore, in the case represented in *Fig. 9*, prefer a dam with core-wall of concrete, as in the dams of the Boston waterworks, the construction of which he had fully described.[1] As no concrete core, and indeed no masonry was perfectly waterproof in itself, it might be protected and made tight by lining it inside with

Fig. 36.



clay puddle. The core-wall then really consisted of two portions, a rigid one and a plastic but waterproof one. This was shown in *Fig. 36*, for which he had adopted the principal dimensions as given in *Fig. 9*. The remainder of the cross-section corresponds to the well-known constructions. The down-stream half of the dam was kept perfectly free from percolation, and would act as a safe buttress. The Author's method of applying drystone toes was certainly a very sound one; only it might probably not be necessary to make the layers so very steep. Slightly-curved layers, concave above, steep at the slope and flat behind, had been employed in constructing the huge drystone toes of large embankments of the railway across the Brenner, and had answered well. They might do just as good service here. He desired to add a

[1] Zeitschrift des Vereines deutscher Ingenieure, 1895, p. 1219 *et seq.*

few words as to the drainage of the base of dam. Slipping must not only be prevented within the mass of the dam, for it might also occur along any surface within the permeable material between the base of the dam and the surface of the rock, inasmuch the more as the latter was frequently covered with a thin layer of wet clay, as slippery as soap. Now, when a surface was liable to become slippery by the access of water, it was obviously of no use to catch the water where it left the slippery surface after it had been running across it. Nevertheless this was in most cases done. The water could only be prevented from rendering such a surface slippery when it was cut off by a drain, before it reached the surface in question. This was the only way of withdrawing the tendency of slipping by simply keeping the proper surface dry. With a view to this fact he had designed a system of drainage (*Fig. 36*) somewhat different from that of the Author. The small drains at the base of the dam, as shown in *Fig. 9*, would not prevent a slipping at some surface between the base of the dam and the surface of the rock, and, moreover, the water had to pass below the whole foundation of the puddle hearting in order to reach the drain. In *Fig. 36* the water was cut off by the main drain running along the axis of the dam before it could reach the base of the concrete wall, and it was then discharged through the pipe conduit. Thus the surface downstream from it, together with the whole stratum of permeable material above it, would be kept as dry as possible. For the sake of safety, he had proposed a second "auxiliary drain" at the toe of the slope of "selected material," parallel to the former, which, together with the puddle-wall W, would certainly keep the whole basing downstream from B dry, so that no slip could arise. The discharge-pipe, or conduit, would be best laid upon the surface of the rock. Should this, however, be too deep, the pipe might be lifted nearer to the ground-surface. By the head required to raise the water in this case, a tendency towards percolation was produced. But since the resistance to percolation into the compressed earth was much greater than that to flowing through the pipe, no sensible soaking was to be effected. Mr. Kreuter.

Mr. E. D. Marten was particularly interested by the account given in the Paper of the enormous floods which had to be dealt with. At the Jamba weir, as stated in Appendix II, a flood was recorded amounting to 373,000 cubic feet per second from a catchment area of 2,050 square miles. This was about the same as the catchment area of the Severn above Worcester, where a bankful flood was only at the rate of about 10,000 cubic feet per second, Mr. Marten.

Mr. Marten. and where the great flood of May, 1886, was calculated to have attained a volume of about 40,000 cubic feet per second. This was the greatest recorded flood at Worcester, and yet its volume was less than one-ninth of that from an equal catchment area on the Jamba. Again, the run off from catchment areas was many times greater than that which had to be dealt with in England. Since the completion of the Vyrnwy dam in 1888, he had received, in his capacity of Engineer to the Severn Commissioners, daily information from their water-bailiff as to the height of the water above or below the crest of that dam, and in the years immediately following 1888, when but little water was being abstracted for Liverpool, he had good opportunities of observing the maximum discharge from the catchment area. The greatest recorded flow was on the 10th December, 1891, when the water discharged into the Severn from Lake Vyrnwy passed over the 456 feet of waste-weir, which was formed by the crest of the dam, with a depth of 1·7 foot, equivalent to a discharge of 215,000 cubic feet per minute, or over 13,000,000 cubic feet per hour. The catchment area was 18,000 acres, so that the discharge was equivalent to a run-off of about $\frac{1}{5}$ inch per hour over the catchment area, and yet, in India, for catchment areas of similar size, it was found necessary to provide for a run-off of 1 inch, or five times as great. The Vyrnwy flood referred to must have been very nearly a maximum flood from the catchment area. The rainfall of the preceding twenty-four hours had been 2·7 inches, and there had been about $\frac{1}{2}$ inch on each of the four preceding days. Moreover, the reservoir had been full and overflowing 5 inches or 6 inches deep for a week previously, so that all conditions were favourable for an extreme discharge. Apparently, therefore, somewhere between four and five times more waste-weir provision would be required in India than in even so wet a district as Lake Vyrnwy. In the early part of the Paper, under heading "Concrete and Puddle-trenches," the Author remarked that, in England, puddle was relied upon to make the concrete beds and walls of service reservoirs watertight. He believed that this was altogether at variance with modern practice and with the necessities of the case. He had recently constructed three service reservoirs of cement concrete without using any puddle, and they were all perfectly watertight, and he was aware of several similar instances. The use of puddle in connection with service reservoirs was objectionable. To be effective, the reservoir must be enclosed on bottom and sides by an unbroken skin of puddle, and this frequently led to subsidences in the floor of the reservoir. To guard

against such subsidences, some engineers had carried footings down through the puddle to the solid ground below it, thus breaking the continuity of the puddle casing, and to all intents and purposes rendering the puddle useless. Mr. Marten.

Mr. L. F. Vernon-Harcourt observed that the Western Ghauts, like all mountain ranges near the sea, arrested the moisture brought from the ocean, so that though there was an abundant rainfall on their slopes, there was a great scarcity of rain in the district, to the east of them further inland. This interception of the rainfall by mountain ranges had proved a serious hindrance to agriculture in the country lying to the east of the Rocky Mountains in North America, and was specially prejudicial in the torrid climate of India, where, moreover, the value of the crops was enhanced by the abundant population and deficiencies in means of communication. The great outflow from the Ghauts during the rainy season was indicated by the deep gorges which intersected their slopes; and the storage of some of this abundant supply was an inestimable benefit for mitigating famines, by its distribution over the parched lands during periods of drought. The reservoirs referred to by the Author had been closed by earthen dams of moderate height; and he advocated the use of those dams for greater heights, with the adoption of special precautions in their construction, in preference to masonry dams. Undoubtedly the cheapness of earthwork in India, and the possibility of utilizing it for famine relief works, as well as the solidity obtained by the basket-work employed by the natives, rendered earthen dams specially suitable for closing reservoirs of moderate depth in somewhat wide valleys; but there must be some sites in the Bombay Presidency where, with rock foundations in a narrow valley, a deep reservoir could be more conveniently and safely formed by a high masonry dam; and the reservoir could be effectually secured from silting up by scouring sluices through the dam near the bottom of the reservoir. Moreover, in the cases where slips occurred, their repair would very materially detract from the apparent economy of earthen dams. Theoretically it would be advantageous to construct a watertight lining on the upstream slope of an earthen dam; but with the variations in water-level and temperature, irrespectively of any settlement, this was not practicable, as a lining of clay or concrete was sure to crack; and the divergence of Indian practice from that in England, in using a large mass of more or less impermeable material in the upstream portion of the dam, seemed to be due to the absence of suitable materials for puddle, rather than to any real objections to the adoption of a central puddle wall. The Mr. Vernon-Harcourt.

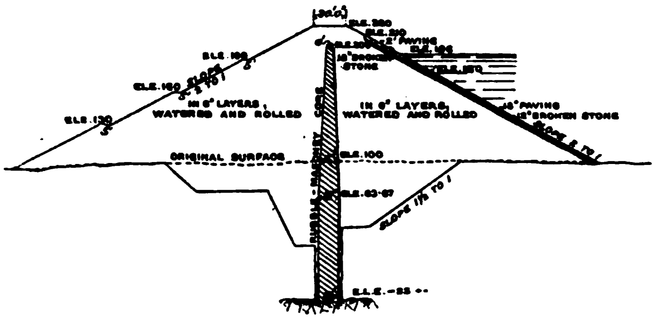
Mr. Vernon-Harcourt. ordinary method of closing earthen dams in India, by rapidly filling up a central wedge from the bottom to the top in the highest part of the dam, was clearly objectionable, as tending to produce unequal settlement and cracks in the central portion of the dam; and the raising of the dam right across in layers, as advocated by the Author, with provision for a temporary waste-weir at the side, was manifestly the proper course. Slips appeared to be not very uncommon on the downstream slope of the dam; but the Author had stated that no slips had occurred on the upper slope of any of the large Bombay earthen dams, showing that ample stability had been secured on the upstream slope. This stability might be attributed to the protection afforded from the sun by the pitching or concrete layer, and its weight, when the water was low in the reservoir, and also the protection of the earth-work from the rains, and the support of the water in the reservoir during the rainy season. The slips on the downstream slope of the dams, besides being aided by the downward slope of the valley, might be caused by the infiltration of the rains into the mass of the dam through the cracks formed by the heat of the sun in the dry season, as in deep railway cuttings through clay, even in the absence of any percolation from the reservoir; and the remedies against such slips were thorough drainage of the mass near its base, and a flattening of the downstream slope, especially towards the base. The stepped waste-weir, proposed by the Author, would have the advantages of affording a more thorough control of the outflow, and enabling the reservoirs to be safely maintained at a higher level. The beneficial action, however, of this type of weir claimed by the Author, of discharging the first floods heavily laden with silt, could only be very partially realised, considering the height of the proposed sluices of the weir above the bottom of the reservoir, as the flood-waters entering the upper end of the reservoir would deposit a considerable portion of their burden of silt in mingling with the water in the reservoir below the level of the sill of the sluices, before being discharged through the sluices.

Mr. Wegmann. Mr. EDWARD WEGMANN thought it would be generally agreed that the design of an earthen dam was to be based more on the results obtained by experience than on theoretical principles. The climate of the country, the storms to which the dam might be exposed, the best materials available for the construction at a reasonable cost, were points that must be considered in designing the profile. He desired to draw attention to high earthen dams that had recently been finished, or were still in process of con-

Mr. Wegmann.

struction, to form storage reservoirs for the city of New York. These dams had generally been built on both sides of central masonry dams or overflow-weirs. As they had been successfully constructed to heights of over 100 feet above the surface (an earthen bank 120 feet high, *Fig. 37*, being now formed as part of the New Croton Dam), it would seem that the French limit of 60 feet for earthen dams might be considerably raised. One of the features of the dams alluded to was that they all contained central core-walls of rubble masonry. This style of construction was adopted owing to the difficulty of finding material suitable for puddle and to the advantages masonry core-walls were thought to possess. Of course, there were many localities where the cost of masonry would preclude its use in earthen dams; but, in comparing the expense of a masonry core-wall with that of an

Fig. 37.



ordinary puddle core, it must be borne in mind that the former was given a much lighter section that the latter. Core-walls of masonry had the following advantages: (1) If founded on an unyielding, impervious stratum of rock, hard pan, &c., such a wall formed a perfect cut-off in the centre of the dam, preventing water that percolated into the inner slope from reaching the outer one. While a good puddle core might answer the same purpose, it was liable to be washed out in case the water found a channel of leakage along the outlet culvert, &c. (2) The core-wall separated a dam into two distinct portions—an up-stream half that should be made as watertight as possible, and a down-stream half that should be formed of porous material. If these different kinds of earth joined each other, cracks might occur in the centre of the dam on account of differences in settling. (3) The outlet

Mr. Wegmann. culvert was usually carried through the dam, as a lateral tunnel for this purpose was generally too expensive. The greatest danger of rupture of an ordinary earthen dam having a puddle core was generally along this culvert. If it was cracked by the settling of the dam, or the puddle was fissured near the culvert on account of differences in settling, water would find its way into the centre of the bank, and would eventually cause its failure unless the damage were discovered in time. With a masonry core-wall there was no difficulty or danger in constructing the outlet culvert through the dam. The reducers of the outlet-pipes were embedded in the masonry wall. The water from the outlet-tower was conveyed to the reducers in a culvert through the inner slope, the outlet-pipes being laid in a similar culvert in the outer slope. A damage to the inner culvert would not jeopardize the safety of the dam. Any leakage that might occur around the reducers owing to careless work, &c., would be carried off by the outer culvert. (4) With a masonry core-wall, an outlet gate-house could be built in the centre of the dam on the up-stream side of the core-wall, to which it was connected. The water was conveyed to this gate-house either in pipes or culverts placed in the inner slope. If the dam was not high, the inner slope might be omitted at the gate-house, the bank on both sides being retained by wing-walls. A gate-house in the centre of a dam had advantages over a water-tower placed in the reservoir, and insured a tight connection for the outlet pipes. (5) A core-wall gave an earthen dam greater strength to resist the erosive action of water passing over its top. Theoretically, such a case should never occur, as every dam was supposed to have a waste-weir sufficient to discharge the greatest floods that might reach the reservoir; but unprecedented rainfalls led occasionally to the failure of dams on account of water flowing over their crests. The greatest disaster of this kind had occurred on the 31st May, 1889, when the dam across the south branch of the Little Conemaugh River in the State of Pennsylvania was ruptured, causing the loss of more than two thousand lives and of millions of dollars' worth of property.[1] The dam in question was about 70 feet high; its top was originally 10 feet wide and 10 feet above the ordinary water-level. The inner and outer slopes were respectively 2 : 1 and 1½ : 1. Watertight earth was used in forming the inner slope and the centre of the dam, but stone was placed in the outer

[1] Report of the Committee appointed by the American Society of Civil Engineers to investigate the cause of the failure. Transactions, June, 1891.

slope. The failure was due to the inability of the waste-weir to pass the water coming from an unprecedented rainstorm. According to competent eye-witnesses, the water commenced to flow over the dam at 11.30 A.M., rising 20 inches over the top. Gradually the water washed a channel at one point through the dam, and rapidly enlarged it until at last at 3 P.M. the dam was ruptured. Considering the fact that the dam withstood the erosive action of the water for 3½ hours, and did not fail until a deep channel was washed through it, it was highly probable that the disaster might not have occurred if the dam had had a masonry core-wall, especially as in this case the outer slope was formed of stone. At all events, it could not be doubted that such a core-wall would give a dam additional strength to resist the erosive action of water flowing over its top. The earth above the core-wall would soon be washed away, but the wall itself would form a long weir which would not fail until the outer slope had been scoured away, and even then the breach made might be comparatively narrow. In designing masonry core-walls, engineers must be guided solely by what experience has shown to be sufficient. It was impossible to calculate the pressures to which these walls were subjected. For high dams, the core-walls were given a stronger section than for comparatively low ones. In the dams built recently in the Croton water-shed, the core-walls had top widths of 2½ feet to 6 feet. Both faces were battered about ¾ inch per foot. The thickness of the wall at the natural surface is made about one-sixth to one-seventh of the depth of the water in the reservoir. From the surface to the bottom of the foundation trenches the walls were vertical. These sections might appear too slight, but they had been found sufficient, even when water percolated to their up-stream faces. In two cases leakage had occurred, not through the walls, but through fissures below the foundations. This leakage had been met by suitable drains, and caused no damage. It would be noticed from *Fig. 37* that the slopes were steeper than those usually adopted in England and India; but the sandy character of the earth, of which the dam was to be composed, permitted such slopes. On some other dams recently built in the Croton watershed the inner slope had been made 2½ : 1. Such a slope was adopted for the earthen part of the Titicus dam, completed about three years ago. Careful observations had shown that this slope had not slid out, the toe remaining in its original position. There had been, however, a gradual settling of the slope proportionate to its height; the maximum being about 2 feet for a height of 102 feet. With argillaceous

Mr. Wegmann.

Mr. Wegmann. earth, the slopes mentioned (2 : 1 to 2½ : 1) would be too steep. He considered core-walls of masonry had advantages which would warrant their use, even at a considerable increase in cost of construction, whenever the available financial means were not too limited. He knew no case of failure of an earthen dam having a masonry core-wall properly built and founded on an impervious stratum. Two dams with core-walls had failed in the United States during the past twenty years; but in one case the wall had not been founded on an impervious stratum, and in the other the wall was exceedingly light and badly built.

Mr. Strange. Mr. W. L. STRANGE, in reply to the Correspondence, was gratified that Mr. J. R. Bell had brought to notice the distinguished service in the late famine of Mr. R. B. Joyner, C.I.E., under whom he had worked, and who agreed generally with his proposals. Bombay was unfortunately situated, in comparison with most other provinces, as being close to the main watershed; even its largest rivers had not a perennial flow of any extent, and storage reservoirs, although expensive, were there a necessity. As regards the "stepped waste-weir," he thought that, on all works of the magnitude of those under consideration, skilled supervision was as great a necessity as it was on railways. His design reduced to a minimum the time during which careful watch had to be kept. He would point out that the system of dry-stone pitching commended by Mr. Bell was due, not to himself, but to Mr. Whiting. The reasons for his own modification of it were given on p. 150. His drains were placed downstream of the centre-line of the dam, that was, far away from the reservoir, to prevent any flow of water being induced by their presence. This distance would effectually prevent the formation of any current sufficient to move particles of the subsoil. Percolation chiefly showed itself at the junction of the dam with the natural surface; it was of very rare occurrence that even dampness was observed on the slope of a well-made dam. Drains constructed as he had specified should not clog. For the reasons given on p. 164, he thought the compound dam more advantageous for deep rocky gorges, except where the gorge was extremely steep. As regards the most suitable works for famine-relief purposes, the objections, noted by Mr. Dunn, were held by many authorities at the end of 1896; but, by the close of the distress, the almost universal opinion in Bombay was in favour of large irrigation works for the employment of the destitute. These were more easily supervised during construction by the small staff available; in normal years they added some wealth to the country, while in abnormal years they might easily produce crops equal to

half or to the whole of their capital cost. If an irrigation work paid its working expenses in normal periods, it might be accepted as a scheme financially sound as regards the country as a whole, although far from being in itself a remunerative one. Each successive famine would thus permanently enrich the country at the expense incurred during and immediately subsequent to its prevalence. During this latter time further assistance to the distressed part of the population would probably be necessary. It must also be remembered that the capital cost of irrigation schemes was very largely increased by the Government system of "indirect charges" debited to them, and this had hitherto greatly minimized the rate of their actual profit-earning capacity. It was pointed out by Mr. Clemens Herschel that ground rollers were employed in America to concentrate the pressure on half their width rather than to assist in kneading and mixing the constituents of the embankment, as he imagined was the object sought by their use. He would prefer increasing the weight of the whole roller, as by a steam roller, so as to secure uniformity of consolidation. A concrete core-wall had once been proposed for the Taílá reservoir, but the proposal was abandoned. So thin a wall might easily be fractured by any unequal settlement of the dam earthwork, and its steep batters would certainly produce a tendency to slipping in the abutting masses of earth which had no bond with it. On the other hand, it might be noted all the American engineers who had dealt with this in the Correspondence were greatly in favour of the system after practical experience of it. The construction of American dams differed much from that of Indian dams, the latter having the advantage of cheap and abundant labour. Mr. John Hopkinson's remarks applied to the total rainfall; but Mr. Strange had in view (p. 130) the individual falls of greatest intensity, which were of more interest from the point of view of the construction of reservoirs. The object of not continuing the drainage of the dam further upstream than the centre line was to interpose a large watertight mass between the drains and the reservoir so as to avoid inducing leakage. The Author was glad to learn that pitching was frequently set in cement in America. If the construction of dams in vertically independent sections, which could each settle without injuring the others, could be attained in practice, the system would have something in its favour, but the great desideratum in all large structures was to have homogeneity and thorough bond. The failure or slipping of one independent part must entail that of the rest. Failures of dams were by no means limited to India, and those which had occurred there were

Mr. Strange.

Mr. Strange. probably due to the very large scale of the works. The actual method of construction adopted was excellent; the chief mistakes that had been made were the use of pure black cotton soil, the system of closure and the small attention paid to drainage. The large discharges to be expected from Indian catchments were due to the intensity of the rainfall, the steep slopes of the country and to the general impermeability of the surface. It was rightly pointed out by Mr. L. F. Vernon-Harcourt that the lowest sluices of the stepped waste-weir, being at a high level, would not act as a perfect means of reducing silting. Owing, however, to the greatly increased size of the upper as compared with the lower contours of the reservoirs, only some 40 per cent. of the capacity of Maladevi reservoir was below the weir under the sluices. In the design he had recently submitted, he had gone further in this direction by providing large under-sluices in the outlet head-wall, below which there was no "available capacity" of the reservoir.

1 February, 1898.

Sir JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S., President, in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Members.

FRANCIS JOHN PRESTON.
WILLIAM ROBERTS.
HARRY READ STOCKMAN.

And that the following Candidates had been admitted as

Students.

WILLIAM BLACKADDER, B.Sc.
CHARLES BEWICKE BLACKBURN, B.Sc.
ALEXANDER DONALD CRAIG, B.E.
JOHN LIONEL CRIDLAN.
CHARLES REEVE DEWHIRST.
CHARLES FISHWICK.
ARTHUR GOULBURN FORBES, B.A.
HERBERT EDWARD HYDE HARRISON.
GERARD SHUCKBURGH HEWETT.
THOMAS HUTCHINSON HIGGINS, B.A.
WILLIAM HUTCHISON.
JOHN MCFARLANE KENNEDY.
SYDNEY FRANK MOTT.
JAMES HASTINGS OTWAY.
BERNARD PRICE.
GILBERT STEPHEN FORDER RUTTY, B.A.
OLIVER ARTHUR GODFREY ST. JOHN-KNELLER.
HOWARD BUCKLEY UNWIN.
JOHN HUW WILLIAMS.
CHRISTOPHER GORDON WRIGHT.

The Candidates balloted for and duly elected were: as

Member.

TOM RICHARD JOHNSON.

Associate Members.

RAYMOND CECIL ALLEN.
JOSEPH NICHOLSON BEATTY, B.E.
THOMAS WILSON BRACKEN.
HENRY GOULBURN WILLOUGHBY CHETWYND.
MORETON JOHN GODDEN COLYER, B.E.
JOHN GRANT-BROWNING.
ARTHUR HASELDEN.
EUGÈNE KINNAIRD HASELDEN.
JOSEPH SLATER LEWIS.
JOHN LEADER MACCARTHY, B.E.
ERNEST MARINUS PROES.
ALBERT EDWARD HARVEY SONNEBORN, Stud. Inst. C.E.
BRYAN STAPLETON.
JAMES STUART.

The discussion upon the Paper by Mr. W. L. Strange, "Reservoirs with High Earthen Dams in Western India," was continued and concluded.

SECT. II.—OTHER SELECTED PAPERS.

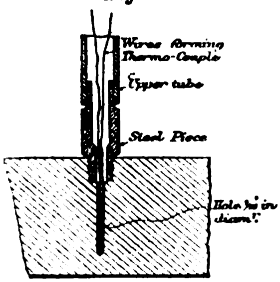
(Paper No. 3043.)

"On the Thermal Condition of Iron, Steel and Copper when acting as Boiler-Plate."

By ELLA MARY BRYANT, B.Sc.

THE object of the investigation described in the following Paper is the determination of the temperature of boiler-plates. Investigations of these temperatures have been made by means of plugs of fusible alloys inserted in the plate, but many objections have been urged against this method.[1] At the suggestion of Dr. Henry Stroud, the measurements of temperature were made by thermo-electric junctions imbedded in the substance of the plate at different depths below the water-surface. In the earlier preliminary experiments, the thermo-electric junctions were inserted in the plate as shown in *Fig. 1*, and the flow of heat through the plate was approximately measured in terms of the weight of water evaporated.

Fig. 1.



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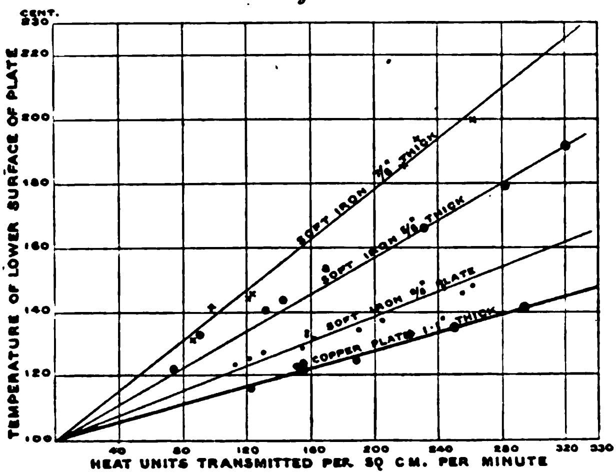
The metals used in these experiments are a soft-iron plate marked B, and a copper plate, and the results obtained are shown in *Figs. 2* and *3*. From these it appears that the temperature of the fire side of a plate transmitting heat to water increases directly as the rate of flow of heat through the plate; and also increases with the thickness of the plate when the

[1] "Expériences sur les Coups de Feu des Chaudières à Vapeur," Hirsch, Ann. du Conservatoire des Arts et Métiers, Paris, 1890 (abstract in Minutes of Proceedings Inst. C.E., vol. cviii. p. 464); Dr. Kirk's letters to *Engineering*, vol. liv. pp. 78 and 333; "The Transmission of Heat through Tube Plates," Transactions of the Institution of Naval Architects, by Mr. A. J. Durston, 1893, vol. xxxiv. p. 130; "Heat Transmission through Metal Plates," by J. G. Hudson, M. Inst. C.E., *The Engineer*, 4 August, 1893, p. 103. For other methods, *cf.* "Boiler Deposits," Professor Lewes, Transactions of the Institution of Naval Architects, vol. xxxii. p. 67, and *Engineering*, 1892. Some experiments of Mr. Blechynden are described in the Proceedings of the N.E. Coast Inst. Engineers and Shipbuilders, 1893. Letter from Mr. Zittenberg, *Engineering*, 14 April, 1893, vol. lv. p. 440.

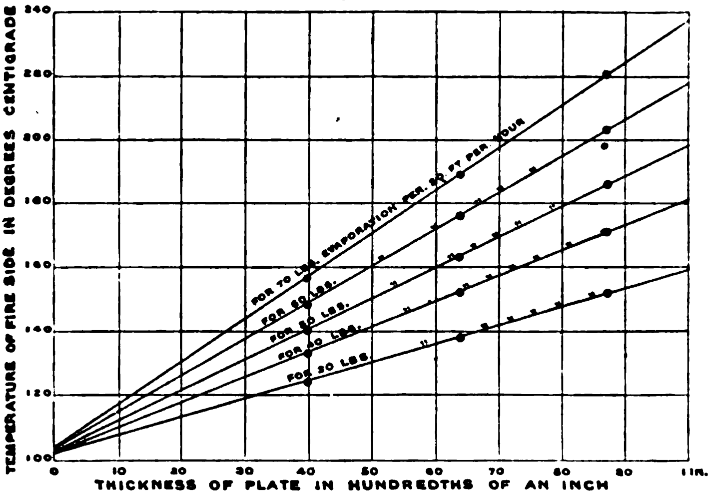
rate of evaporation is constant. The water-surface of the plate

Fig. 2.



CURVES SHOWING THE TEMPERATURE OF THE FIRE SIDE OF THE PLATE AT DIFFERENT RATES OF EVAPORATION.

Fig. 3.



CURVES SHOWING THE INCREASE OF TEMPERATURE OF THE FIRE SIDE OF THE PLATE WITH INCREASE OF THICKNESS AT DIFFERENT RATES OF TEMPERATURE.

was found to be between 3° C. and 12° C. above the boiling-point of water.

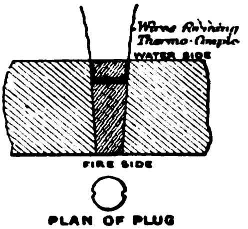
T 2

In the later experiments several alterations were made in the apparatus, and in the methods of measurement.

The Galvanometer.—Instead of measuring the electromotive force of the thermo-electric junctions by the potentiometer method, direct readings were taken by means of a Deprez-D'Arsonval galvanometer, and it was possible to read to 0·2° C. A calibration curve was drawn for each couple, using the known boiling-points of steam (100° C.), aniline (184° C.), and naphthalene (218° C.). For higher temperatures the necessary resistance was added to the circuit, the calibration points being the melting-points of aluminium (625° C.), and potassium sulphate (1066° C.).

Method of Inserting the Junctions.—It was important that the insertion of the junctions should not affect the distribution of heat in the plate. Several methods were tried without success, but that finally adopted, *Fig. 4*, seems free from serious objection. A small plug of circular section, of the same metal as the plate, was made to fit into a slightly tapered hole so that its ends were level with the surfaces of the plate. Two holes, $\frac{1}{16}$ inch in diameter, were drilled lengthwise on opposite sides of the plug to the desired depth, and they were connected by a horizontal hole of the same diameter. There were six such plugs arranged in a circle of $1\frac{1}{4}$ inch radius round the centre of the plate. The junction forms a bead fitting loosely into the horizontal hole in the plug, and is fixed in position by solder. The remaining space of the holes is filled in with very fine Portland cement. It was hoped that the clean metallic contact between the plug and the plate would be watertight, but it was found necessary to use a little rubber solution. The connecting wires from the junction are covered by asbestos within the holes, and pass directly up through the water enclosed within rubber tubes. The depths, measured from the centre of the horizontal hole at which the junctions were inserted, are given in tabular form on p. 277.

Fig. 4.



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Measurement of the Water Evaporated.—To ensure that the flow of heat through the plate should be vertical only, from the surface exposed to the furnace to that in contact with the water, use was made of the "guard-ring" principle. The form of apparatus, together with the method of measuring the water evaporated, had been suggested by Mr. Hirsch's Paper. The inner vessel A, *Fig. 5*, has for its base the plate which is the subject of experiment; the

STEEL PLATE.

Thickness, 2·56 centimetres = 1·01 inch.

Depth Below Water-Surface.		Distance from Fire-Surface.		Depth Below Water-Surface.		Distance from Fire-Surface.	
Centi-metre.	Inch.	Centi-metre.	Inch.	Centi-metres.	Inch.	Centi-metres.	Inch.
1·86	0·734	0·70	0·276	0·18	0·070	2·38	0·940
0·65	0·257	1·91	0·750	1·05	0·415	1·51	0·595
1·45	0·570	1·11	0·440	2·34	0·920	0·22	0·090

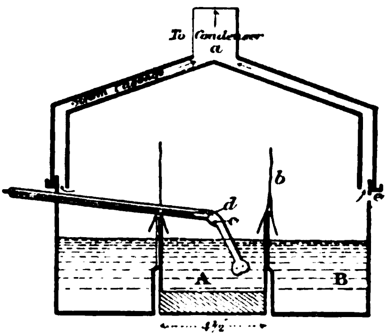
COPPER PLATE.

Thickness, 2·30 centimetres = 0·905 inch.

Distance from Fire-Surface.		Depth Below Water-Surface.		Distance from Fire-Surface.		Depth Below Water-Surface.	
Centi-metres.	Inch.	Centi-metre.	Inch.	Centi-metre.	Inch.	Centi-metres.	Inch.
2·16	0·850	0·14	0·055	0·97	0·383	1·33	0·522
1·78	0·700	0·52	0·205	0·48	0·188	1·82	0·717
1·36	0·535	0·94	0·370	0·15	0·058	2·15	0·817

guard-ring, consisting of an outer annular vessel B, is made of sheet copper. The inner vessel A slips into the central aperture of B, which is not cylindrical, but of slightly greater diameter at the base, to admit of a lining of non-conducting material between the two vessels, in order to prevent flow of heat from the plate to the water in the outer vessel. The cover forms a steam-jacket, and the steam passes to a condenser through the opening at *a*, thus preventing loss of heat by radiation from the inner vessel. The division between the two vessels is extended by means of a mica cylinder (*b*), which is doubled so that any water projected against it would be returned to the vessel whence it came. The

Fig. 5.



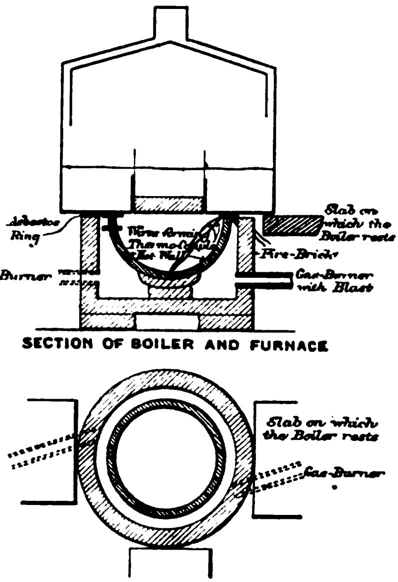
Scale, 1½ inch = 1 foot.

SECTION THROUGH THE BOILER.

siphon *c* connects the inner vessel A with a beaker of water, and the level is kept constant by means of a Mariotte bottle, so that the water evaporated from vessel A is given by the fall in height of the water in the Mariotte bottle. This height is measured in a small tube attached to the bottle, and the weight of water corresponding to any difference in height is found by weighing the bottle and its contents. A mercurial thermometer *d* placed in the siphon gives the temperature of the water when entering the inner vessel.

A furnace of fire-brick surrounds a hollow iron hemisphere on which the boiler rests with an asbestos washer interposed (*Figs. 6*). The heating is effected by two Fletcher oxygen burners, placed so as to project the flames on the outer surface of the radiating hemisphere tangentially, thus rendering the heating uniform. An air-blast is used, and, for higher temperatures, oxygen is mixed with the air. The temperature of the radiating surface of this hemisphere is measured by thermo-electric junctions, either resting on its inner surface, or, in later experiments, embedded in the substance of the metal. With this arrangement the heating of the conducting plate is chiefly due to radiation from the oxidized surface of the hemisphere, but there would be a certain amount of circulation of air in the hemispherical space enclosed.

Figs. 6.



PLAN OF FURNACE

Scale, 1 inch = 1 foot.

FURNACE WITH BOILER IN POSITION.

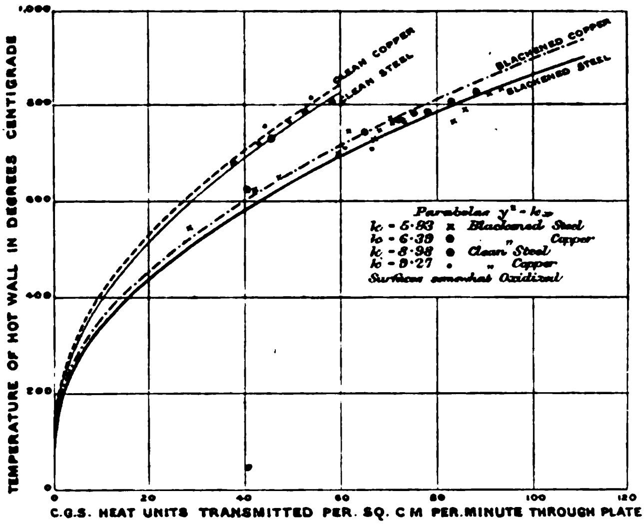
Duration of the Experiments.—The furnace was lighted and evaporation continued until the temperatures, both of the plate and of the hot wall, remained steady. The times given in the Table were those during which the measurements recorded were taken, although the whole experiment was of much longer duration.

The results of the experiments are given in Tables I to IV and

TABLE I.—COPPER PLATE. THICKNESS, 0·904 INCH = 2·3 CENTIMETRES. AREA, 96·3 SQUARE CENTIMETRES.

Date, 1896.	Temperature of Hot Wall in ° C.	Heat-Units Transmitted per Minute.	Lbs. of Water Evaporated per Square Foot per Hour.	C.G.S. Heat-Units per Square Centimetre per Minute.	Temperature of Water-Surface in ° C.	Temperature of Lower Surface in ° C.	Difference of Temperature between Upper and Lower Surfaces in ° C.	Duration of Experiment in Minutes.	Condition of Surface.
Nov. 7 I	759·5	4,220	10·0	43·9	102·6	107·0	4·4	20·0	Oxide.
„ 7 II	770·0	4,680	11·1	48·6	102·6	107·1	4·5	12·0	„
„ 12 I	820·0	5,170	12·3	53·7	..	..	..	28·5	„
„ 12 II	723·0	4,090	9·9	42·5	103·6	108·0	4·4	20·0	„
„ 13 I	769·0	6,970	16·6	72·3	105·0	111·6	6·6	17·0	Slightly blackened.
„ 13 II	786·0	7,240	17·2	75·2	105·1	111·2	6·1	14·5	Slightly blackened.
„ 15 ..	627·0	3,820	9·8	39·7	104·0	106·8	2·8	24·0	Smoked.
„ 18 I	746·0	6,260	14·9	65·0	106·8	112·1	5·3	30·5	„
„ 18 II	773·0	6,890	16·4	71·6	106·7	112·5	5·8	31·5	„
„ 18 III	787·0	7,510	17·9	78·0	106·8	112·7	5·9	22·0	„
„ 19 I	807·0	7,990	19·0	83·0	107·2	113·2	6·0	15·0	„
„ 19 II	825·0	8,540	20·3	88·6	107·8	113·8	6·0	15·0	„

Fig. 7.



CURVES SHOWING THE VARIATION OF HEAT TRANSMISSION WITH THE TEMPERATURE OF THE HOT WALL.

in *Figs. 7* and *8*. Table 1 and *Fig. 7* give the results of a series of experiments with a copper plate. The plugs used were turned from a copper-rod, both this and the plate being of "commercial pure copper." Had it been possible a portion of the plate should have been used for the plugs, as copper-rod and plate may differ in conductivity. The water-surface was washed between each experiment, and, although not a bright metallic surface, it did not alter in character. The lower surface of the plate was in some cases clean and bright before the experiment, but became tarnished and had a mottled appearance, due to condensation; in other cases it was covered with lampblack.

The temperatures of the hot wall given are the means of a number of observations, differing sometimes as much as 10° during an experiment. The change of temperature was frequently not more than 3° during ½ hour.

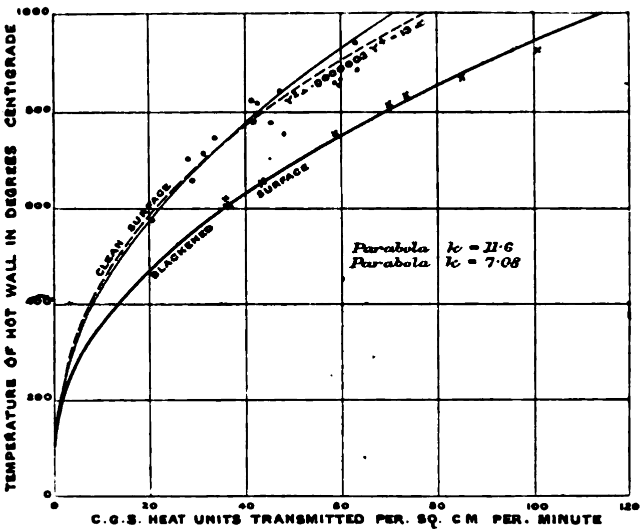
The results of experiments made under similar conditions with a soft-steel plate are given in Table II and *Fig. 7*. The water-

TABLE II.—STEEL PLATE. THICKNESS, 1·015 INCH = 2·58 CENTIMETRES. AREA, 105·4 SQUARE CENTIMETRES.

Date, 1895.	Temperature of Hot Wall in ° C.	C.G.S. Heat-Units Transmitted per Minute.	Lbs. of Water Evaporated per Square Foot per Hour.	C.G.S. Heat-Units per Square Centimetre per Minute.	Temperature of Water-Surface in ° C.	Temperature of Lower Surface in ° C.	Difference of Temperature between Upper and Lower Surfaces in ° C.	Duration of Experiment in Minutes.	Condition of Surface.
Nov. 30 ..	775·0	8,780	19·1	83·4	107·0	139·8	32·8	26·0	
Dec. 2 II	701·0	6,280	13·6	59·6	108·8	137·6	28·8	29·0	
" 2 III	750·0	7,180	15·6	68·1	109·0	141·0	32·0	23·5	
" 2 IV	773·0	7,420	16·5	70·4	109·6	144·1	34·5	9·0	Smoked and a
" 2 V	778·0	8,310	18·1	78·9	110·0	145·3	35·3	12·0	little rusted.
" 4 ..	796·0	9,090	19·8	86·2	107·9	147·5	39·6	24·5	
" 5 I	731·0	7,060	15·4	67 0	105·4	135·8	30·4	22·5	
" 5 II	648·0	4,815	10·5	45·6	103·9	125·8	21·9	13·0	
" 7 I	711·0	6,910	15·0	65·6	108·0	134·0	26·0	17·0	Rusted round the edges and smoked.
" 7 II	621·0	4,380	9·9	41·5	107·0	124·9	17·9	12·5	
" 12 I	834·0	9,640	21·0	91·5	108·1	143·2	35·1	18·0	Somewhat irregularly rusted and smoked.
" 12 II	841·0	9,820	21·3	93·2	108·1	144·8	36·7	22·5	
" 12 III	748·0	6,470	14·1	61·4	106·8	133·4	26·6	13·0	
" 13 I	766·0	7,450	16·2	70·7	105·2	135·0	29·8	33·0	Rusted chiefly at edges and smoked.
" 13 II	545·0	2,920	6·4	27·8	104·0	116·8	12·8	21·0	
" 14 ..	793·5	5,460	11·9	51·9	106·5	131·0	24·5	16·0	
" 16 I	807·0	6,040	13·1	57·3	105·5	129·9	24·4	31·0	Rusted slightly
" 16 II	688·0	3,930	8·5	37·3	104·3	120·9	16·6	20·5	all over. No
" 17 I	834·0	7,380	16·1	70·1	104·7	134·8	30·1	32·5	smoke.
" 17 II	736·0	4,710	10·2	44·8	105·3	124·7	19·4	21·0	

surface was cleaned before each experiment and was fairly clean throughout. The lower surface was always more or less rusted, even when it was covered with lampblack, and when clean at the commencement it always became covered with a reddish film of oxide. In some experiments the lower surface of the plate was rusted in patches, so that some of the plugs had their lower ends black and others rusted. The result was an irregular temperature distribution within the plate; the junctions in those plugs whose ends were blackened having relatively high temperatures. Such experiments were rejected, but they are interesting as they show

Fig. 8.



CURVES SHOWING THE VARIATION OF HEAT TRANSMISSION WITH THE TEMPERATURE OF THE HOT WALL.

the great effect of the condition of the surface. Similarly any irregularity in the upper surface of a plug was found to lower the temperature reading of its junction.

Tables III and IV and *Fig. 8* refer to the same steel plate, but with its surface free from rust. While the boiler was being heated before an experiment, a blast of air was sent into the hemispherical space below the plate. This prevented the hot gases from coming in contact with, and condensing upon, the cold iron, and thus prevented the rusting. This blast was stopped before the measurements were taken, as if left on it largely

increased the circulation of air, and the result was an increase of evaporation for the same temperature of the hot wall. The temperatures of the hot wall were given by a junction imbedded in the metal, and are probably more correct than those given in the previous Tables.

TABLE III.—STEEL PLATE. THICKNESS, 2·56 CENTIMETRES. AREA, 105·4 SQUARE CENTIMETRES.

Date, 1896.	Temperature of Hot Wall in ° C.	C.G.S. Heat-Units Transmitted per Minute.	Lbs. of Water Evaporated per Square Foot per Hour.	C.G.S. Heat-Units per Square Centimetre per Minute.	Temperature of Water-Surface in ° C.	Temperature of Lower Surface in ° C.	Difference of Temperature between Upper and Lower Surfaces in ° C.	Duration of Experiment in Minutes.	Condition of Surface.
Feb. 20 ..	942·5	6,581	14·3	62·96	104·9	135·0	30·0	20·0	Clean surface throughout.
Jan. 31 I	887·0	6,698	14·6	63·57	108·4	136·0	27·6	26·0	
Feb. 7 I	869·0	6,287	13·7	59·67	107·0	134·5	27·5	34·0	
Jan. 27 ..	860·0	6,172	13·4	58·58	105·6	130·3	24·7	21·0	
Feb. 21 I	854·0	6,219	13·5	59·03	105·5	132·0	26·6	20·0	
„ 10 ..	844·0	4,903	10·7	46·54	106·7	126·0	19·3	25·0	
Jan. 16 ..	825·0	4,290	9·3	40·72	105·5	125·0	19·5	14·0	
Feb. 3 I	820·0	4,410	9·6	41·86	108·0	127·0	19·0	26·0	
„ 21 II	776·0	4,711	10·2	44·71	105·5	126·6	21·1	21·0	
Jan. 30 I	747·0	3,441	7·49	32·66	107·0	123·8	16·8	34·5	
„ 30 II	710·0	3,208	6·98	30·45	106·5	121·3	14·8	19·0	
Feb. 3 II	700·0	2,909	6·33	27·61	106·2	119·4	13·2	32·0	
Jan. 31 II	660·0	2,521	5·49	23·93	107·0	118·8	11·8	34·0	
Feb. 21 III	660·0	2,945	6·41	27·95	104·1	118·5	14·4	25·5	
„ 7 II	584·0	2,119	4·61	20·11	104·4	114·6	10·2	32·5	
Jan. 29 ..	781·5	4,315	9·38	40·96	107·5	128·0	20·5	25·5	

TABLE IV.—STEEL PLATE. THICKNESS, 2·56 CENTIMETRES. AREA, 105·4 SQUARE CENTIMETRES.

Date, 1896.	Temperature of Hot Wall in ° C.	C.G.S. Heat-Units Transmitted per Minute.	Lbs. of Water Evaporated per Square Foot per Hour.	C.G.S. Heat-Units per Square Centimetre per Minute.	Temperature of Upper Surface in ° C.	Temperature of Lower Surface in ° C.	Difference of Temperature between Upper and Lower Surfaces in ° C.	Duration of Experiment in Minutes.	Condition of Surface.
Feb. 11 II	927·0	10,644	23·1	101·03	107·0	154·0	47·0	9·0	Smoked.
„ 11 III	871·0	8,944	19·5	84·89	107·2	145·4	38·2	9·5	„
„ 11 I	834·0	7,732	16·8	73·39	108·2	142·2	34·0	22·0	„
„ 12 II	656·5	4,507	9·5	42·78	105·8	128·1	22·3	27·5	„
„ 12 I	603·0	3,755	8·2	35·69	105·0	123·0	18·0	20·5	„
June 8 I	815·0	7,366	16·0	69·90	106·7	136·7	30·0	23·0	„
„ 8 II	753·0	6,158	13·35	58·42	106·2	133·5	27·3	9·0	„
„ 8 III	622·0	3,715	8·05	35·24	105·0	121·6	16·6	23·0	„

In *Figs. 7* and *8* parabolas are drawn passing nearly through the points representing the results given in the Tables I and II and III and IV respectively.[1] It will be seen that all the results follow nearly the parabolic law—

$$k\,\mathrm{H} = (\mathrm{T} - 100)^2,$$

where H is the number of heat-units transmitted per square centimetre per minute, and T the temperature of the hot wall in degrees Centigrade.

A comparison of the curves in *Fig. 7* shows that, when both surfaces are blackened for the same temperature of the hot wall, the evaporation through the steel plate was greater than that through the copper, and thus the superior conductivity of the latter gives it no appreciable advantage in this respect. With surfaces covered with oxide the effects are nearly the same for the two plates, and the evaporation in both cases is much less than with blackened surfaces.

A comparison is afforded in *Fig. 8* between the effects of a clean and of a blackened surface exposed to radiation. Irregularities in the clean surface have caused the results to be somewhat irregular, but it will be seen that, while those for the blackened surface follow very nearly the parabolic law, those for the clean surface deviated considerably from it. In every case the evaporation increases somewhat more rapidly than it would if the parabolic law were exactly followed, and the Author finds that Mr. Blechynden's results deviate from this law in an exactly similar way, although the mode of heating and the methods of measurement which he adopted are very different from those now described. With a blackened surface the heat is almost entirely supplied by radiation, and the curve is very nearly a parabola. With a clean surface the heat supplied by convection becomes relatively more important and the deviation from the parabola is increased. An experiment arranged so that the hot gases acted directly on the plate showed a deviation from the parabolic law in the same direction and of very much greater amount. A possible explanation of this is that while the heat gained from radiation is proportional to the square of the difference of temperature between

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[1] "An account of some Experiments on the Transmission of Heat through Steel Plates, &c.," by A. Blechynden, Transactions of the Institution of Naval Architects, 1894, vol. xxxv. p. 70; "The Transmission of Heat through Metallic Plates," *Engineering*, 1 January, 1897, vol. lxiii. p. 30, describing experiments at Riechsantalt by Dr. Wiebe and R. Schwirhus.

the surfaces, that due to convection is more nearly proportional to a higher power of this difference. Attempts to measure precisely the actual temperature of the gas when it strikes the plate were not successful. Any temperature between the highest in the furnace and one very near that of the surface of the plate, *i.e.*, about 160° C., could be obtained by placing a junction at different positions in the hot gas, and it was evident there was a layer of cold gas next the plate.

A curious effect was noticed during the experiments. On several occasions when the vessel boiled dry, a sudden fall of the temperature of the plate, especially near its upper surface, occurred, followed by a rapid rise. The cooling is evidently due to rapid evaporation taking place when the water is nearly boiled away, and is followed by a rise of temperature as soon as the surface is dry.

Conductivity of the Metals Tested.—Columns 5 and 8 of the Tables show the relation between the difference of temperature between the surfaces and the rate of flow of heat through the plate. This affords a direct measurement of the conductivity of the metal. For copper, the value deduced from Table I is $0{\cdot}50 \pm 0{\cdot}15$ C.G.S. unit. For the steel plate from Table II, the conductivity $= 0{\cdot}098 \pm 0{\cdot}011$ C.G.S. unit. From Tables III and IV, the conductivity $= 0{\cdot}095 \pm 0{\cdot}006$ C.G.S. unit.

Table V gives the results of a series of experiments with the copper plate in which the gases were allowed to strike directly on the plate. One or two minor precautions were neglected. The mean conductivity deduced from these is 0·40 C.G.S. unit. The conductivity of copper thus found is roughly double that of Péclet, but his value almost certainly errs in defect owing to an error which had been pointed out in Depretz's Table of relative conductivities, which affects Péclet's result. The earlier rough experiments gave 0·10 C.G.S. unit for the conductivity of a soft-iron plate—a result which is consistent with the above and obtained by a different method.

It is remarkable that, while the relative conductivities of copper and iron thus obtained agree with those given by experiments on bars, the absolute values are considerably smaller. The value for iron is nearer that of Péclet (0·08 C.G.S. unit), who used a plate of metal and a method similar in principle to that described. Péclet's low result has been attributed to error introduced by the resistance of the surfaces; but he stated that he had experimented with plates of different thicknesses, and found the flow of heat inversely proportional to the thickness of the plate, which could

only be the case if the surface resistance were negligible.[1] Either, then, the conductivity of iron measured across a plate differs from that measured along a bar, or the conductivity of different samples varied over a wide range; or, more probably, the thermal conductivity of iron along the grain is different from that across the grain.

TABLE V.—COPPER PLATE. THICKNESS, 0·904 INCH = 2·3 CENTIMETRES. AREA, 96·3 SQUARE CENTIMETRES.

Date, 1895.	C.G.S. Heat-Units transmitted per Minute.	Lbs. of Water Evaporated per Square Foot per Hour.	C.G.S. Heat-Units per Square Centimetre per Minute.	Temperature of Water-Surface in ° C.	Temperature of Lower Surface in ° C.	Difference of Temperature between Upper and Lower Surfaces in ° C.	Duration of Experiment in Minutes.	Condition of Surfaces.
Oct. 25 I	10,070	24·0	104·6	108·0	122·3	14·3	12·5	Smoked.
„ 25 II	11,840	28·2	123·0	109·0	123·3	14·3	11·0	„
„ 25 III	13,810	32·8	143·4	108·6	122·0	13·4	11·0	„
„ 24 I	14,430	34·3	149·9	106·3	124·0	17·7	47·0	„
„ 22 I	9,560	22·7	99·3	105·7	118·6	12·9	29·0	Not smoked.
„ 22 II	6,550	15·6	68·0	104·9	114·6	9·7	12·5	„ „
„ 21 I	10,680	25·4	110·8	107·8	119·8	12·0	11·0	Smoked.
„ 21 II	4,700	11·2	48·9	106·0	112·3	6·3	40·0	„
„ 17 ..	12,110	28·8	125·7	107·0	118·1	11·1	30·0	„
„ 16 ..	9,590	22·8	99·6	105·0	114·8	9·8	36·0	„
July 23 ..	15,320	36·4	159·0	104·6	120·1	15 5	12·0	„
„ 23 I	14,140	33·6	146·8	106·2	119·0	12·8	14·0	„
„ 23 II	16,050	38·2	166·7	106·5	120·6	14·1	10·0.	„
„ 25 I	15,040	35·8	156·1	105·4	118·7	13·3	23·0	„
„ 25 II	..	..	..	107·1	121·9	14·8	22·0	„

Surface Effect.—A number of experiments were then made to determine the effect of oil on the water-surface or forming a coating on the surface of the conducting plate. The plate was dried, well oiled with sperm oil, vaseline, best sweet oil or gas-engine oil, and the water was put in and the boiler set on the fire. Most of the oil came to the surface of the water, and if a film remained on the surface of the plate it was not sufficient to produce any appreciable effect in raising its temperature. The plate having been oiled was then heated to about 200° C. before the water was put in. The oil turned brown but had no more effect than before. A thin layer of lime deposited on the plate had no effect on the temperature of the surface, but when oiled with the gas-engine oil the surface-temperature rose about 2° C.

[1] Péclet's "Traité de la Chaleur," vol. iii., 3rd edition, 1861.

higher than it would have been if it had been clean. When the surface was oiled with gas-engine or sperm oil, and then heated up to 200° C., the temperature rose some 4° C. But variations produced in this manner were not much greater than those which occurred when the surfaces were kept as clean as possible. The oil rendered the measurements difficult but showed no reduction in the evaporative efficiency owing to the oily surfaces.

Linseed oil, sperm oil and best sweet oil were then treated in the following manner. A small quantity of the oil was put in the boiler and heated till it decomposed and a dark brown waxy layer was formed on the surface of the plate. It was of uneven thickness, but was of the order of $\frac{1}{100}$ inch. When water was evaporated under these conditions there was a marked rise in the temperature of the upper surface of the plate, the maximum rise of temperature being about equivalent to what would have occurred if about 0·7 inch of iron had been added to the thickness. No abnormal effects were produced, as these are fully accounted for by the low conductivity of the decomposed oil.

The above experiments show that the distribution of temperature in the plates is exactly what would be predicted from the law of conduction. That the conductivity of steel or iron plates may be below 0·1 C.G.S. unit, and that of copper below 0·5 C.G.S. unit. That the heating effect of radiation on a surface is approximately proportional to the square of the difference of temperature between the surfaces.

Note on Fusible Plugs.—The method of finding the temperature of the plate by means of fusible plugs had been criticized in several ways. In Mr. Hudson's Paper it is suggested that a sudden rise of temperature of the lower side of the plate takes place just before the water begins to boil, thus melting the plugs and indicating a higher temperature than that reached during evaporation. To test this suggestion, the indications of a thermo-junction near the lower surface of a plate were watched during the heating, and no such effect was observed. The temperature rose steadily until boiling occurred, and reached a steady state when it had continued for some time. On the other hand, the objection that the plate is at a lower temperature than the plugs owing to resistance to the flow of heat offered by the surface between them is confirmed by comparison with the thermo-electric method.

Plugs and thermo-junctions were inserted in the same plate and their temperature indications were compared. Mr. Hirsch's description of the methods of inserting the plugs of alloy, and of finding their melting-points, was carefully followed, but the alloys

used were not found to melt at definite temperatures; so that measurements were only possible within somewhat wide limits. The following results are, however, sufficient to show that temperatures obtained by the method of fusible plugs are far in excess of those given by the thermo-electric junctions.

TEMPERATURES OF LOWER SURFACE OF PLATE.

By Thermo-junctions.	By Plugs.
112·5° C.	About 123° C.
123·5° C.	Between 139° C. and 149° C.
130·0° C.	Above 161° C.

The earlier work was carried out in the laboratory of the Durham College of Science, Newcastle, under Professor Henry Stroud, D.Sc., and the later work in that of the Royal College of Science, under Professor Roberts-Austen, C.B., Assoc. Inst. C.E., and Mr. H. C. Jenkins, Assoc. M. Inst. C.E., for whose kindness and help the Author is deeply grateful.

The Paper is accompanied by six drawings, from which the *Figs.* in the text have been prepared.

(*Paper No. 3015.*)

"Re-erection of the Albert Bridge, Brisbane."

By Henry Charles Stanley, M. Inst. C.E.

The Albert Bridge, carrying the Southern and Western Railway across the River Brisbane, Fig. 1, Plate 4, was built in the years 1875–76 for a double line of railway. It consisted of eight spans, the principal one, of 160 feet, over the mid-channel, having iron lattice-girders of the hog-back type; the remainder were formed of parallel lattice-girders—six spans of 80 feet each and one shore span of 40 feet at the northern end. The seven piers were each formed of two cast-iron cylinders, connected above low-water level by wrought-iron horizontal struts and diagonal braces. These cylinders were 8 feet in diameter up to the level of low water, above which they tapered to 5 feet diameter at the under-side of the caps. They were filled with cement concrete to a height of 13 feet above high water or at the level of the highest flood—that of the year 1864—which had been experienced prior to the erection of the bridge. The cylinders of the piers on the north side of the 160-foot span were sunk into the solid rock, and those on the southern side were founded in cemented gravel at depths varying between 30 feet and 40 feet below the river-bed. The abutments were built of ashlar masonry, that at the northern end of the bridge being on rock, whilst the foundation of the other was formed upon a bed of cement concrete, 3 feet thick, 12 feet below the surface of the ground in alluvial formation, protected by sheet piling. The total cost of the structure was about £52,000.

The flood-level of 1864 was 32 feet 6 inches below rail-level, or 30 feet from the under-side of the main girders; but a still more severe flood occurred in the year 1890, which rose 15 feet higher. During the month of February, 1893, the south-eastern portion of the Colony of Queensland was visited by floods of unprecedented severity, when the water reached to within 21 inches of the bottom boom, or 28 feet 3 inches higher than the flood-level of 1864. On the morning of the 4th February, after several days

of exceptionally heavy rainfall, the river at Indooroopilly had risen nearly to the level of the flood of 1890, and, in order to assist the bridge to resist the abnormal strain to which it was subjected, a train of loaded wagons was placed on the up-stream line. This expedient had been resorted to during the flood above-mentioned with good effect, and in this instance also materially assisted to steady the structure. Considerable oscillation being observed in pier No. 6, at the north end of the 160-foot span, which carried the expansion-rollers and was exposed to the strongest current, the precaution was taken to drive steel wedges between the rollers so as to prevent movement in them, and this for a time had the desired effect. Shortly afterwards a settlement was found to have taken place in the second pier from the south abutment, and traffic over the bridge was consequently at once suspended. This pier disappeared during the night, its foundation being completely undermined, as was afterwards ascertained, by the excessive scour in the river-bed, which extended to a depth of over 40 feet. The girders resting on this pier, although not continuous, were riveted to the adjoining spans at the ends over piers Nos. 1 and 3, and remained undisturbed after piers Nos. 2 and 4 disappeared; in fact, they were afterwards utilized in lieu of staging upon which to erect one of the spans of the new bridge. Pier No. 4 also failed early on the following morning, carrying with it the 80-foot span on the north side. About mid-day on Sunday, the 5th February, pier No. 5, which supported the southern end of the 160-foot span, succumbed, carrying the girders and their load of trucks with it. The two spans on the northern bank of the river resisted the first rush of flood-waters, but were swept away by a second rise which took place in the river a fortnight afterwards. Thus all that remained of the bridge were four of the 80-foot spans, resting on the two alternate cylinder piers Nos. 1 and 3, the attachment of the rails serving to balance them at the unriveted ends.

The causes of failure in the case of the piers to the south of the principal span are not far to seek, for the enormous scour in the river-bed had either undermined the cylinder foundations, or left them so denuded as to be incapable of resisting the rush of flood-waters, the current of which was estimated at between 9 miles and 10 miles an hour, combined with the impact of large masses of debris, including numerous houses and other wooden buildings. The cause of the collapse of the other piers on the northern bank of the river, which were all sunk into the solid rock, can, however, only be conjectured. It can be shown that, theoretically,

the piers as designed had a large margin of stability, and it is therefore probable that the struts and bracing connecting the cylinders must have been injured or destroyed by the repeated blows of trees and other floating bodies brought down by the flood; so that, becoming independent columns, they were by themselves unable to withstand the abnormal pressure to which they were subjected. The piers were broken off a few feet above the surface of the rock.

After the flood had subsided divers were employed to ascertain the position and condition of the submerged superstructure with the following results:—The 80-foot span which fell with pier No. 4 was found to be lying completely inverted diagonally across the stream about 200 feet below the bridge and some 50 feet nearer the southern bank than its original position. The principal span of 160 feet had been deposited across the channel at a distance of 240 feet from the bridge and was found to have been considerably damaged. The remaining 80-foot and 40-foot spans from the north end of the bridge were located about 130 feet below the northern abutment, on the rocky bed under the north bank, and were reported, with the exception of the footway, to be but slightly injured. It was at first hoped that the superstructure, or at least some portions of it, might be recovered, and tenders were invited for carrying out the work. It was subsequently found, however, that the cost of raising the girders, &c., would be greater than their value, and it was therefore decided to abandon them.

The New Bridge.

In view of the excessive scour in the river-bed, which there can be little doubt was in a large measure due to the obstruction caused by the numerous piers of the old bridge, the Author deemed it advisable that in re-building the structure an entirely new design should be adopted providing for only two spans and one central pier, Figs. 2, Plate 4. It had been observed that the main strength of the flood-waters was along the northern bank of the river, and that a strong back current, caused by the configuration of the ground, set up-stream on the opposite side, thus leaving the site to be occupied by the central pier comparatively clear of the full force of both currents. A series of borings having been made at the site of the pier, it was ascertained that a solid rock foundation could be secured at a depth of 27 feet below the river-bed, or about 80 feet from high water.

The bridge as designed and now erected is adapted for a double

line of railway, of 3-foot 6-inch gauge, and consists of two spans of 340 feet each, resting on masonry abutments, and a central pier, also of masonry, built on a wrought-iron caisson filled with cement-concrete to within 1 foot of low-water level. A footway for passengers, 5 feet wide, is carried on cantilevers, supported on the bottom booms of the up-stream girders. The level of the rails has been raised 5 feet 6 inches above that of the old bridge, giving a clear height of 49 feet above high-water level to the underside of the main girders, or 7 feet above the level of the flood of 1893.

Abutments.—The new design involved the raising and widening of the abutments so as to adapt them to the larger structure. It therefore became necessary to remove a portion of the outer masonry of the old abutments, leaving the remainder as a core round which the extended new masonry was built. The whole of the facework consisted of ashlar masonry, and was backed with cement concrete composed of 1 part of Portland cement, 2 parts of sand and 4 parts of broken stone. The stone used for the masonry, both in the abutments and the central pier, was an excellent freestone of a light-brown colour obtained from quarries at the foot of the main range, near Helidon Station, on the Southern and Western Railway, 72 miles west from Brisbane. Before deciding to adopt this stone it was subjected to careful tests, which gave the following results:—

Weight per cubic foot	142 lbs.
Specific gravity	2·27
Absorption of water	4 per cent.
Crushing weight per square foot	295 tons.

The building of the abutments was commenced in October, 1893, and they were finished to the level of the bedstones by the following May. The parapets were not built until the superstructure of both spans had been placed permanently in position. They were finally completed in November, 1895. The bedstones for the girders were formed of a close-grained and extremely hard grey granite, weighing 165 lbs. per cubic foot, obtained at Mount Crosby on the Brisbane River, some 15 miles above the site of the bridge. Those on the central pier were in one stone, each measuring 9 feet long by 5 feet wide and 18 inches deep, and before being dressed weighed nearly 7 tons.

Centre Pier.—The foundation of this pier may be regarded as the most important work connected with the bridge. It consisted of a wrought-iron caisson, Figs. 3, Plate 4, of elliptical shape, the major axis of which was 51 feet and the minor 21 feet 6 inches.

The outer wall was constructed of $\frac{3}{8}$-inch plating, riveted to horizontal and vertical tee-bars strongly braced together, and forming a hollow watertight space 4 feet wide, designed to act as a buoyancy-chamber. The outer and inner plates converged at the base so as to form a cutting-edge, which was finished at the bottom with a $\frac{5}{8}$-inch steel plate. There were two double cross walls, also made watertight, connecting the opposite sides of the caisson, thus dividing it into three working-chambers for the removal of the material brought up by dredging and of the rock excavated. As it was intended that no portion of the ironwork should be visible above water-level, a temporary top was provided and bolted to the upper flange of the caisson, so as to allow of the masonry being built up within it to high-water level. After the masonry reached this level, the temporary top was removed. The complete caisson weighed 230 tons, whilst the weight of the temporary top was 9 tons. The lower part, 20 feet in height, weighing 70 tons, was first fitted and bolted together in the contractor's yard on the Indooroopilly or northern side of the river. It was afterwards riveted up on a timber slipway constructed for the purpose on the opposite bank, and after one or two ineffectual attempts, it was finally launched on the 27th June, 1894. Before launching, 4 tons of fine concrete were filled into the bottom of the outer wall to act as ballast, and when afloat the caisson drew 10 feet of water. As dredging operations for the removal of the cylinders of the original piers, which were lying across the site of the new pier, were then in progress, the caisson was in the meantime moored alongside the temporary pier supporting the outer end of the 80-foot girders of the old bridge, in order that the work of building might be continued without interruption. Some delay arose in removing the remains of the cylinders of the old piers, owing to their being covered by a deposit of gravel and sand. After this had been cleared away by dredging, the broken parts of the cylinders were removed in succession by being slung with chains to large punts. An attempt was made to remove by the same method the base of the other cylinder which had been broken off, but this was found to be impracticable, and dynamite had to be used to break it up, after which the pieces were easily cleared away. On the 9th August, the caisson, then drawing 36 feet, was floated into position at the site of the new pier; guide-piles having first been driven to assist in the operation of sinking. As the framework and plating were built up, the caisson was gradually sunk, by filling the outer wall with concrete. It touched the bottom on the 2nd September, when it was drawing 52 feet $2\frac{1}{2}$ inches, and

dredging was then carried on from the inside by Priestman and Milroy grabs. On the 22nd of the following month rock was reached and the work of excavation had thereafter to be accomplished by divers. This part of the work being performed under water, at a depth of 80 feet below the surface, proved tedious as well as hazardous to those employed. The rock, consisting of slate, traversed by numerous quartz veins, was extremely hard in parts, and the contractors experienced much difficulty in obtaining divers able and willing to work under the somewhat high pressure (40 lbs. per square inch). Some of the men suffered severely from "pressure pains," whilst others were obliged to desist altogether after one or two trials. Work was generally carried on in 4-hour shifts with gangs of five men. The supply of air was obtained from an accumulator, constructed out of an ordinary cylindrical wrought-iron boiler, into which it was forced by a compressor. The pipes to which the several air-tubes were attached were each fitted with a pressure-gauge and stop-cock, so that the amount of air required by the divers could be readily regulated and controlled. The whole apparatus was contained in a punt moored alongside the staging round the caisson and was covered by a light roof. The arrangement met with much favour with the divers, who stated that the air supplied them was much purer than is the case with the ordinary method of hand-pumps. Whilst sinking was in progress, a delay of a fortnight was caused by a fresh in the river, the water rising above the top of the caisson. Precautions had previously been taken to sheet in the top with planking, to prevent silt from being deposited, and no damage resulted. The total time taken in sinking the caisson was 163 days, of which 127 working days were occupied in actual operations.

In order to secure a level bed upon which the caisson might rest, a trench was excavated in the rock, 4 feet wide, and averaging 2 feet deep. On the 19th February, 1895, it was found that the bottom of the caisson was bearing uniformly and the work of filling with concrete was at once started. Owing to the strong tidal current it was considered advisable to deposit the concrete round the cutting-edge in bags, but after this was effected the rest was lowered into position by the usual method of boxes with movable bottoms. When about 20 feet of the caisson had been thus filled, the water was pumped out, and the remainder of the concrete was inserted dry. The concrete in bags was composed of 1 part of cement, 1 part of sand, and 2½ parts of blue-metal chippings; that deposited in water of 1 part of cement, 2 parts of

sand, and 4 parts of broken stone, whilst the remainder, which was filled dry, was formed of 1 part of cement, 3 parts of sand and 6 parts of stone. The concreting was completed to within 1 foot of low-water level on the 26th March, and on the 1st April the setting of the masonry commenced. By the 15th of that month the pier had been carried up to high-water level and the temporary top of the caisson was then removed. The top of the permanent caisson is 9 inches below low-water level, and 73 feet 9 inches above the level of the cutting-edge as it rests upon the rock. Above the level at which the concrete stops, the pier, like the abutments, is built of ashlar masonry face-work with concrete backing. Above the level of high water an intake course reduces the form of the pier from an ellipse to a rectangle which is gradually battered, on the sides and down-stream end, to the underside of the plinth course. The up-stream end is built vertically and forms a cutwater which is protected by granite quoins. The masonry of the pier was finished to the level of the bed-stones on the 26th June.

The total height of the pier from the bottom of the caisson to the level of the bed-stones is 129 feet, and the maximum pressure on the base is calculated at 7,600 tons. This is equivalent to a pressure of 8·82 tons per superficial foot, or if the displacement of the pier is allowed for (the skin friction in the river-bed being disregarded), of $7\frac{3}{4}$ tons. The pressure on the masonry at high-water level is equal to $5\frac{3}{4}$ tons per square foot, and on the granite bed-stones of 16 tons per square foot.

Superstructure.—The superstructure is built entirely of mild steel, except the footway girders, which are of wrought iron. The main girders are 340 feet long with segmental upper booms, and a central depth of 41 feet 6 inches, which is reduced to 21 feet 6 inches at the ends. They are divided into twenty panels of 17 feet each by vertical posts with a double system of web bracing, having counter braces in the six centre panels. The main girders are placed 27 feet apart, from centre to centre, or 24 feet 4 inches in the clear between the bottom booms. The top booms are connected by horizontal braces and diagonal wind-ties, and sway bracing is also provided between the posts. The cross girders have a central depth of 2 feet, and are suspended directly to the lower ends of the vertical posts. They support trough girders in which the longitudinal sleepers are bedded in bitumen and sand. Diagonal wind-ties are placed on the top of the cross girders, and the trough girders are strongly connected transversely to each other, and to the bottom of the main girders, by

steel tee-bars, which also carry the planks forming the decking of the bridge. All the principal connections of the various members composing the girders, cross girders, and rail-bearers are made by machine-closed steel rivets, the holes for which were all solid-drilled from carefully prepared templets. Only in a few unimportant parts was punched and rimered work permitted, and hand-riveting was only allowed when it was impracticable to apply the pneumatic riveter. The work performed by this riveter was most satisfactory, the heads being more regular in shape, and the rivets better closed than by hand. The following comparison of work performed by the machine and that by hand in a day of 9 hours may be of interest:—

PNEUMATIC MACHINE.

Lower flange, cross girders and posts	500 $\frac{7}{8}$-inch rivets	In the yard.
Cross girders and posts	1,000 $\frac{3}{4}$ " "	In the yard.
Lower boom	369 $\frac{7}{8}$ " "	After erection.
Main tie-bars	144 $\frac{7}{8}$-inch and $\frac{3}{4}$-inch rivets	After erection.

HAND-RIVETING.

Bottom of posts	70 $\frac{7}{8}$-inch rivets	In erection only.
Top boom	92 $\frac{7}{8}$ " "	In erection only.
Main tie-bars and trough girders .	180 to 200 1-inch to $\frac{3}{4}$-inch rivets	In erection only.

NOTE.—The figures refer to the average number of rivets closed during a period of 31½ days.

The work in the boom-plates probably gives the fairest comparison, and, in that case, it will be observed that the number of rivets closed by the machine is about four times that by hand. The difficulty in moving the machine, especially on the top of the girder, and the imperfect appliances used for that purpose, account for the small number of rivets returned for the main tie-bars.

The comparative costs of riveting with the machine and by hand were found to be:—

Machine—the result of 31½ days' work in the yard, giving an average of 500 rivets per day	6*s*. 5·2*d*. per 100
Hand-riveting	21*s*. 8·5*d*. "

A trial was made of an oil-furnace for heating the rivets, and as the result, as many as 1,618 rivets were inserted by one machine in 6¾ hours, the consumption of kerosene oil being about 15 gallons. The cost of the latter, 2*s*. 6*d*. per gallon, or over ¼*d*. per rivet, being considered too expensive, it was discontinued. It is only fair, however, to say that two riveting

machines could as easily have been fed by the same consumption of oil, but the condition of the work did not render this possible.

Stresses.—For the purpose of calculating the stresses in the component parts of the girders, Figs. 4, Plate 4, the rolling load was assumed to consist of two of the heaviest locomotives in use on the railway—weighing 52 tons in steam—on each line in the centre of the span, with fully-loaded trucks covering the remainder of the span in either direction. This was equivalent to a central load on each girder of 147·87 tons, or a distributed load of 0·87 ton per foot. The panel load was taken at 32 tons, representing 15 tons of moving load and 17 tons of dead load. The maximum intensity of unit stresses under the full load in the several members are:—

	Tons per Square Inch.
Booms in compression	6·5
„ tension	7·0
Vertical struts	5·0
Diagonal ties	6·5
Wind-bracing	8·0
Cross girders	6·5
Rail-bearers	6·5

Wind-Pressure.—The wind-pressures adopted in the calculations were as follows:—(*a*) Lower system. Moving load:—A pressure of 30 lbs. per square foot upon a train surface of 10 square feet per foot of the girder. Fixed load:—A pressure of 30 lbs. per superficial foot on twice the exposed area of the main girder, divided between the top and bottom flanges, but only reckoned for the bottom flange. (*b*) Upper system. Fixed load:—A pressure of 50 lbs. per square foot upon twice the exposed area of the main girder, divided between the top and bottom flanges, but only reckoned for the top flange. The total maximum pressure sustained by the girder at one time will vary accordingly as the bridge is occupied by a train load, or is empty, and is calculated to be 92·4 tons with a train load (lower system); and 78·2 tons when the bridge is empty (upper system). The panel load allowed for in the upper system is 3·9 tons, and in the lower system 4·62 tons. The steel for the girder work was tested to a breaking strength of between 30 tons and 34 tons, and the rivet steel to 28 tons per square inch, with elongations of not less than 18 per cent. and 25 per cent. respectively in a length of 8 inches. The bearings are of cast steel, of a tensile stress of 45 tons to 50 tons per square inch. Fixed bearings are placed on the centre pier and are formed with 9-inch steel pins, accurately turned, to act as rockers, so as to allow motion due to deflection or longitudinal movement in the

girders, Figs. 5, Plate 4. The free or expansion bearings occur on the abutments, and are of similar construction, except that they rest upon a series of segmental rollers turned to bear truly upon the planed surfaces of the saddle and lower bed-plates, Figs. 6. These rollers have sufficient play to allow 5 inches of movement in each direction. In estimating the amount of expansion in the girders, a range of temperature of 188° F. was allowed for; with a coefficient for steel of 0·000006 for expansion and contraction this gives 4·6 inches in the length of the girder. The total weight of steel in the superstructure of one span, including the cast-steel bearings, is 590 tons, or about 1·72 ton per foot; and the weight of a span, with the footpath and decking complete, is 685 tons. The steel plates and bars for the girders were imported from England, but the shaping, fitting, and drilling was performed by the contractors in shops erected for that purpose near the northern bank of the river at Indooroopilly. The bearings of the main girders were, however, cast and planed in England. The steel reached the colony in February, 1894; but as the drills and other machinery only arrived at the same time, and the caisson plates had first to be finished, the girder work was not started till the beginning of April. The latter was completed all but a few tons erected by June, 1895, so that the average output was 77 tons for the 15 months' work. During the greater part of the time drilling was carried on night and day.

Erection.—It was considered undesirable, not only on account of the obstruction to navigation but of the risks from floods, to allow temporary staging to be erected across the river; and the contract therefore provided that the northern span should either be floated or launched into position, whilst the remaining spans of the old bridge were to be utilized in erecting the girders on the south side.

North Span.—Preparatory to being launched the girders were erected partly in a cutting adjoining the northern abutment, convenient to which the shops had been located, and partly on staging extending from the abutment to the river bank and for a short distance beyond. Launching ways were laid on a carefully prepared foundation, Fig. 8, Plate 4. For this purpose trenches were excavated in the line of the girders and were filled with river gravel to a depth of 12 inches. On this gravel a platform of railway sleepers, laid longitudinally, was formed, and resting on these were transverse timbers 10 feet by 14 inches by 12 inches, 2 feet 3 inches apart from centre to centre. The latter supported two longitudinal sleepers, 15 inches by 7 inches, on each of which two 60-lb.

rails were spiked. The trolleys carrying the shore end of the girders were formed of three baulks of ironbark timber, 14 feet long by 18 inches by 18 inches, bolted together, and supported on four pairs of cast-iron wheels with centre flanges, and keyed to 6-inch diameter steel axles. The staging which supported the outer end of the span, Fig. 7, projected sufficiently into the river to allow of the vessel used in launching to be floated into position under the ends of the girders. As a precautionary measure, to provide against the possibility of this staging being swept away by flood, so much of the girders as rested upon it and projected beyond the river bank were temporarily strengthened by struts and ties with a view to their being capable of supporting their own weight as cantilevers. It was at first intended to build a stage on two pontoons secured side by side with which to support the ends of the girders when being launched, but the contractors preferred to employ the hull of a barque of 800 tons burthen, which they purchased for the purpose. Her dimensions were: length 200 feet, beam 35 feet and depth 23 feet.

The erection of the girders of the north span was completed on the 23rd May, 1895; but, owing to the masonry of the centre pier being unfinished, the launching of the span had to be postponed until the following month. Arrangements were completed to carry this out on the 27th June, but in consequence of a high westerly wind it was not considered advisable to attempt it on that day. On the following Saturday, the 29th, however, the weather being favourable and everything in readiness, the vessel, on which a substantial staging had been erected, was floated at low water (11.45 A.M.) under the end of the span, and by 2.20 P.M. the tide had risen sufficiently to enable her to take the weight of the span and lift the girders off the blocks upon which they rested. Steps were at once taken to remove the outer portion of the staging adjoining the river bank, and the work of launching commenced at 4.20 P.M., and continued without the slightest hitch or difficulty until 5.40 P.M., when the ends of the girders had been brought over their permanent bearings on the central pier. The distance travelled was 75 yards, so that the average speed was 2 feet 9¾ inches per minute. By 7 P.M. the ends of the girders had been blocked up on the masonry of the pier, but it was not till midnight that the ship could be floated clear of the bridge. The latter operation was attended with some difficulty, as the fall of the tide was barely sufficient to release the weight off the staging, and it was only by driving out

the wedges, which had been placed under the packing below the girders, that it was eventually effected.

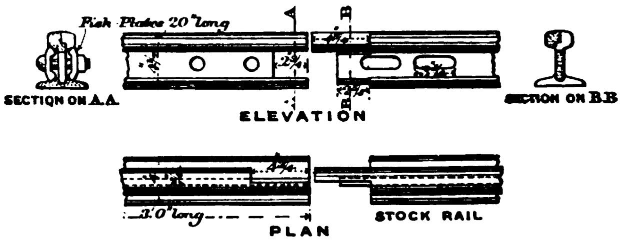
The principal power applied in hauling was derived from a triple-purchase 10-ton hand-power winch fixed to the decking of the old bridge, the steel hawser from which was attached to the ends of both of the main girders. Two 5-ton hand-power winches were also provided on the deck, the wire ropes from which were secured on the south side of the river, whilst guys were also carried from the ship to the north bank. The latter, however, were chiefly useful in maintaining the vertical position of the ship and staging. Every precaution had been taken to ensure the stability of the hull. She was ballasted with about 200 tons of sand, and heavy hardwood logs were hung by chains from each side. A plummet was suspended from the top of the staging between the girders and the deck so that any variation from the perpendicular could at once be detected. As an additional safeguard, wire-rope stays had been attached to the bottom booms of the girders and to the foot of the staging on each side and drawn taut by union screws. Sighting-rods were erected in the centre-line of the bridge, and the central position of the ship was regulated by means of mooring cables carried up and down stream. No difficulty was experienced in keeping the girders in line, and the divergence did not at any time exceed a few inches. The displacement of the ship had been carefully calculated, and when the full weight—about 300 tons—was taken, the extra draught did not exceed that calculated by more than ½ inch.

South Span.—One of the first operations undertaken by the contractors when entering upon the work was the erection of temporary timber piers under the unsupported ends of the 80-foot spans of the old bridge. This enabled them to utilize the roadway for the conveyance of stone and other material from the south side of the river to the site of the centre pier, whilst a steam crane was fixed at the outer end of the superstructure. For the erection of the girders a timber platform was constructed across the top booms of the old girders on which the camber blocks were laid. The girder work was commenced in February, 1895, but could not be completed until the masonry of the centre pier was sufficiently advanced to permit of the steam crane being removed. This was effected on the 2nd July, after the pier had been finished to bed-stone level. The riveting of the outer end of the girders was then pushed rapidly forward, and by the 31st July the removal of the superstructure of the old bridge was commenced.

The new span was blocked up off the abutment and pier, whilst the various sections into which the old girders had been cut were lowered by tackle, secured to the bottom booms of the new girders, into punts in the river beneath. On the 7th August everything had been cleared, and arrangements were made for lowering the span on to its permanent bearings. This was carried out satisfactorily by hydraulic jacks on the 10th of the month, and a week later, the rails having been laid and connected on each side, the bridge was ready for testing.

Expansion-joints are provided in each rail at the ends of both spans adjoining the abutments, *Figs.* 9. They are constructed with short pieces of rail, 3 feet long, having a sliding joint at each

Figs. 9.



Scale, ¾ inch = 1 foot.

EXPANSION JOINT FOR 60-LB. RAIL.

end, each of which have a play of 2½ inches, thus providing for a maximum movement in the girders of 5 inches.

Testing the Bridge.—The first test to which the bridge was subjected was the application of a stationary load of four locomotive engines weighing 52 tons in steam, two on each line, placed in the centre of each span successively, and fully-loaded trucks covering the remainder of the span in both directions. The load was 527 tons. Following upon this two trains, each having two locomotives drawing loaded trucks sufficient to entirely cover one span, of a weight of 263 tons, were run in opposite directions at a speed of 30 miles an hour, so as to pass as nearly as possible in the centre of each span in succession. The deflection in the girders was carefully noted by means of levels placed on either abutment, as also by the aid of a fine steel wire stretched between the abutments and centre pier. In the case of the latter the deflections were read off upon scales attached to battens fastened to the posts at the centre and at each quarter of the span. Theodolite observations were also taken to ascertain the

amount of lateral movement in the girders induced by the passing loads. The following Table gives the results of these tests :—

—		North Span.		South Span.	
		Up-stream Girder.	Down-stream Girder.	Up-stream Girder.	Down-stream Girder.
Stationary load .	. deflection in inches	1·92	2·04	1·74	1·95
Running load	. " "	1·32[1]	1·68[1]	1·68	1·20
Permanent set	inch	0·12	0·12	0·48	0·36

The girders were built with a camber of 6⅜ inches at the centre, but this was reduced to 5⅜ inches under their own load. The lateral vibration in the girders did not exceed $\frac{1}{10}$ inch on each side from the position of rest under the running load. Two days after the bridge was tested the "up" line of rails was opened for traffic, the down line being reserved for the contractors' use whilst completing the parapets of the abutments and decking of the bridge and footway. The whole work was completed and handed over by the contractors on the 5th December, 1895.

Cost.—The contract for the bridge, including certain protective works on the south bank of the river, amounted to £65,186, and the total expenditure on the work, including the alterations in gradient at each approach, necessitated by the raising of the bridge, preparation of plans and supervision, amounted to £70,894.

In conclusion, the Author desires to record his acknowledgments to Professor W. H. Warren, M. Inst. C.E., of the Sydney University, whom he consulted in regard to the calculations, as also for the assistance rendered by the Resident Engineer, Mr. F. L. Keir, Assoc. M. Inst. C.E., in preparing the working drawings and afterwards superintending the erection of the bridge.

The Paper is accompanied by five tracings from which Plate 4 and the *Fig.* in the text have been prepared.

[1] Trains did not pass exactly in centre of span.

(*Paper No. 3048.*)

"Surveys and other Preliminaries to Railway Construction in New South Wales."

By Charles Ormsby Burge, M. Inst. C.E.

The railway system of New South Wales, which is worked by the Government, now comprises a length of 2,576 miles, on the standard gauge of 4 feet 8½ inches; a private line of 45 miles on the Victorian gauge of 5 feet 3 inches, forming an isolated extension of the Victorian railway system into New South Wales, and at present unconnected with her lines, constituting an immaterial exception.

For the last 8 years, the construction has been controlled by the Department of Public Works under the Minister for Works, who, in consequence of the policy of practically all public works being undertaken by the Government, is one of the leading members of the Cabinet; and the working and maintenance are carried on by three railway commissioners, holding office for 7 years, to whom the lines, when finished, are handed over. The following has been, for some years past, the procedure antecedent to the construction of a railway in New South Wales. Application is made, generally through petition or deputation, by a local railway or progress league, representing the community requiring the line, to the Minister for Works, who, if concurring as far as investigation is concerned, instructs the engineer-in-chief to have the country examined and reported upon. On this report, if fairly favourable, a trial survey and plans are made, and are followed by an estimate. A report by the railway commissioners is also called for as to the prospects of the line from their standpoint, it being remembered that, in the case of railways projected by governments, as distinguished from those undertaken by private enterprise, two considerations have to be kept in view, namely: (1) the development of the country as to resources and population, the increase in the latter diminishing in a large degree the relative cost of its government; the increased value of unsold crown lands; the gain resulting from the difference between the

cost of conveyance of commodities and passengers by a bad road as against that by a good railway, with the expensive maintenance of the bad road which is superseded, and finally, the question of intercolonial or strategical connections, all of which are the business of the general government; and (2) the prospect of the proposed line being remunerative to the taxpayers, as shareholders of the railways, which is more particularly the care of the railway commissioners. These two objects are generally, but not necessarily always, reached by the same means, as the former may be obtained by a line which is worked at a loss, judging from the railway balance-sheet alone.

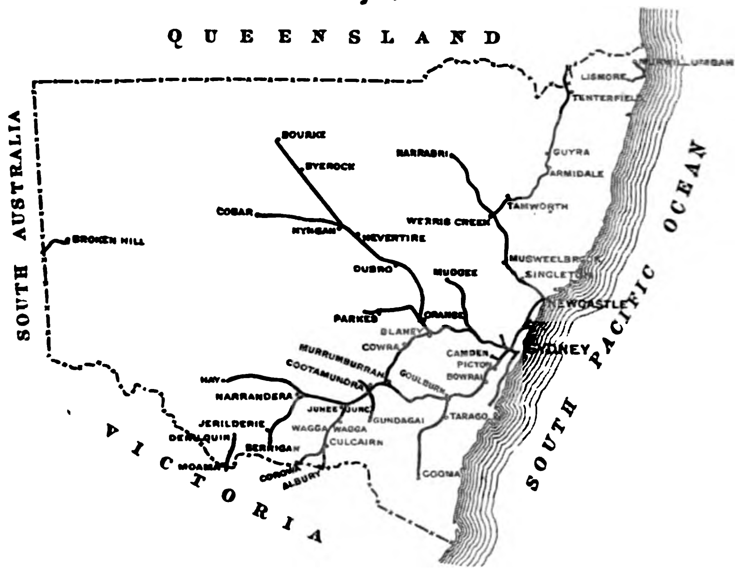
The Minister then brings his case, with the above data, before Parliament, which, if it approves, refers the question to the Parliamentary Standing Committee on Public Works. This body was created, some years ago, to deal with the construction of all public works of which the estimated value exceeds £20,000. They are elected from their own number by Parliament, thirteen in number, eight being from the lower, and five from the upper house, and they examine witnesses as to the merits of the proposal from all points of view, a sub-committee generally visiting the district and taking local evidence.

Assuming the ordeal successfully passed, a bill is brought into Parliament, and, if carried through all its stages of three readings in each house, becomes law through the Governor's assent. Contrary to usual English practice, where all is left to the select committees, there is frequently an animated debate in both houses on the second reading of the bill. The permanent survey, or staking, follows the passing of the bill, and when plans are ready and while lands are being acquired, tenders for construction are invited. The expenditure for surveys previous to the Act of Parliament, is charged to a variable but annual vote for railway trial surveys; that incurred after the Act is debited to the special vote for the line in question, and is therefore considered in the estimate.

As regards the survey operations, it should be noted that there is hardly any branch of engineering science which has made such strides in advance, in recent years, as that of railway location. It is now more thoroughly understood that the extra expenditure in employing competent men, and in spending sufficient time in working out the several problems that present themselves in the prosecution of such work, is trifling in comparison with the benefits derived from such a course in lessening the cost of construction and of working.

The surface of the colony of New South Wales is more varied generally than that of others of the Australian group, and a high range of country, having considerable width, runs parallel to the coast, at a distance varying between 50 miles and 100 miles. As this is the most densely inhabited part of the country, and hence the best provided with railways, and as the range varies between 2,000 feet and over 4,000 feet above sea-level, throwing out long and numerous spurs, it will be readily understood that the railway surveys there have required considerable skill in their inception and completion, while those in the interior of the colony, which is

Fig. 1.



Scale, 1 inch = 240 miles.

Map of New South Wales, showing Railways open for Traffic.

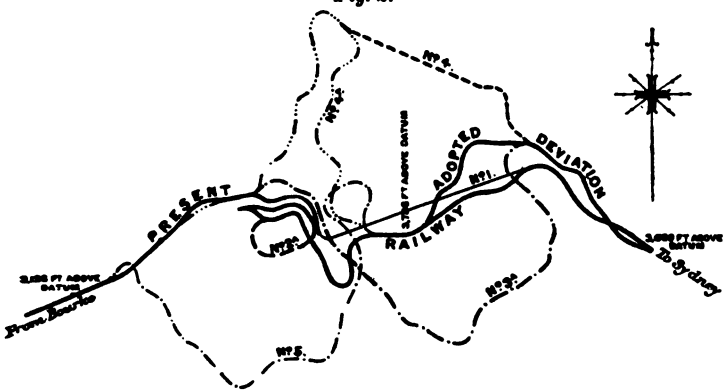
generally flat, have tested, from the intense heat, and the severity of the droughts, the endurance and pluck of the railway surveyors to an extreme degree. Altogether, there has been carried out, in somewhat over 40 years, though mostly in the latter half of it, including all classes of surveys, about 16,330 miles, estimates having been made to the extent of about £69,000,000, *Fig. 1*. Ascents to ranges over 400 feet in height, river crossings such as the Hawkesbury—where the largest bridge[1] in the southern

[1] Minutes of Proceedings Inst. C.E., vol. ci. p. 2.

hemisphere has since been erected, and where the alignment and distances had to be computed, measurement across the estuary being impossible—and long straights over generally waterless plains in the west, which, however, have to be chosen so as to minimize risk of destruction by occasional floods extending sometimes 20 miles in width, are problems that are being continually faced; while several city and suburban railway projects, among valuable properties and crowded streets, with proposals for tunnels under, and bridges across, Sydney harbour, bring out wholly different attainments in their design.

Among the earlier problems surmounted were the ascent to the coast range of the western main line and the descent towards the western plains beyond, which were accomplished by zigzags, or

Fig. 2.



Scale, 1 inch = 2 miles.

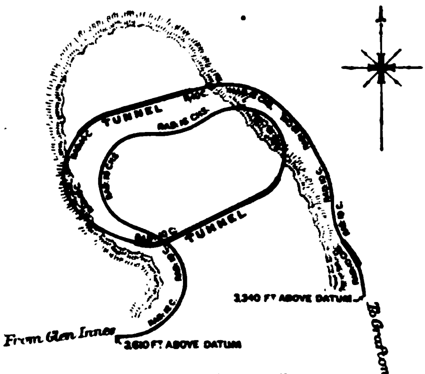
Proposed Lines to supersede the Great Zigzag, Great Western Railway, N.S.W.

switchbacks. Though they formed undoubtedly, at the time of construction many years ago, by far the best solution of the question, on account of their cheapness and sufficiency for the traffic of many years to follow, as experience has amply proved, these expedients involve, with increasing traffic, heavy working expenses and a certain risk of accident, especially in the middle road, where every train is back-shunted on a heavy gradient. One of these, the eastern, has already been superseded by a through-tunnel line, the saving in working expenses being much more than the interest on the outlay, which was under £50,000. The ruling gradient on the ascent is 1 in 30.

A plan of the alternative lines proposed for the supersession of the larger western zigzag is shown in *Fig. 2.* The old gradient

of 1 in 42 with 8-chain curves and the reverse middle road are proposed to be superseded by one of the longer, 1-in-60, through lines with 15-chain curves in proposals Nos. 3*a*, 4, 4*a* and 5. No. 1 contains a tunnel 2,816 yards in length. The advantage of the latter line is that it is the shortest, except No. 1, a considerable gain to the descending traffic. It is very much the cheapest, and the cost of working the up-traffic by assistant engines which is contemplated in this proposal, even with a large prospective traffic, would be much less than the interest on the extra cost of construction of the cheapest of the 1-in-60 schemes. The subsequent adoption of a deviation of the present line covered by some of these routes, as shown in *Fig.* 2, reduces the choice now to that between Nos. 2*a*, 4*a* and 5. All these proposed alternatives are very heavy, with numerous tunnels.

Fig. 3.



Scale, 1 inch = ¼ mile.

Spiral on the Proposed Glen Innes-Grafton Railway.

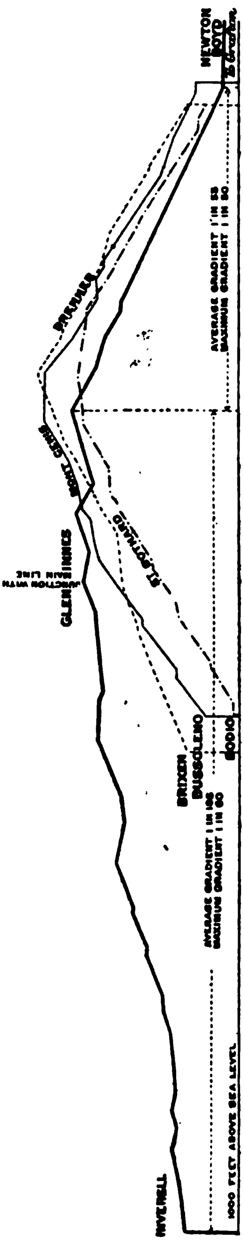
As other examples of the Colonial railway surveys may be mentioned a group of alternative lines connecting the railways of the table-land or coast range, referred to above, with the northern ports of the colony, the contention of which latter for preference in this matter, no doubt, as well as the great cost involved, having delayed construction. In one of these a descent is made of 2,600 feet in 27 miles, with a ruling gradient of 1 in 50 and 10-chain curves, and the whole length of 115 miles abounds in tunnel work and sharp curvature. Near the summit-level a spiral alignment, in order to give length to ease the gradient, is adopted, two long tunnels being included in the spiral, *Fig. 3.* By a spiral tunnel approximating to a more strictly circular form on the ruling gradient of 1 in 50 the line could have been let down in a considerably shorter distance, but ventilation would have been impracticable, and the loss of adhesion in the tunnel would have virtually increased the ruling gradient to a large extent. By elongating the spiral at right angles to the axis of the narrow spur which is utilized for its location the gradient is eased by the additional length

given, and the tunnel work is shortened and broken into two parts. This will facilitate ventilation, which also will be the less necessary than on the steeper gradient, where, in ascending, the products of combustion from the locomotive would be greater. The estimate for the line amounts to £1,660,668. To show the magnitude of this work a section of the gradients is shown in *Fig. 4* of this line and its continuation westwards to the lower interior country, in comparison with those of the three Alpine railways, Mont Cenis, St. Gothard and the Brenner.

In the south of the colony, access from the same table-land to the coast has been the subject of somewhat similar rival projects; but in this case, as only one port is aimed at, the choice of route is of a more strictly engineering character. In one of these, 65 miles long, the main descent is proposed to be bunched into a rack-rail section, 4½ miles long, with 1 in 12 gradient units, by which a vertical distance 1,800 feet is descended in that distance. The above types are exceptional, the most numerous class of lines surveyed being of a more ordinary character.

The trial surveys are carried out by parties consisting, ordinarily, of one surveyor with four men and a cook; and, as the country is not sufficiently populated to afford accommodation, the party lives in camp, which is moved on as the survey proceeds. The surveyor, after due examination of

Fig. 4.



Horizontal Scale, 1 inch = 16 miles; Vertical Scale, 1 inch = 3,200 feet.

GRADIENTS ON PORTION OF PROPOSED INVERELL-GRAFTON RAILWAYS, COMPARED WITH THOSE OF ALPINE RAILWAYS.

the country, instructions from headquarters, and co-operation with the other surveyors, if any, on the same line, runs a traverse for a portion of the length within reach of his camp, taking cross-levels reduced to the general datum, numerous or otherwise, according to the nature of the ground, and sends up, together with a section of the traverse, a preliminary plan with the traverse and cross-levels written upon it, to the head office, also indicating upon it a suggested alignment. This is approved or amended there, and is returned to the surveyor, who is meantime preparing the preliminary plan, &c., of the next length, or exploring ahead. He then sets out the approved line, and takes the section over it, marking the aligument thoroughly by pegs and tree-cuts, &c., so that it may be established again after years—a very necessary precaution. The description of these marks is entered on the plan, so that, should the project be in abeyance during any of its preliminary stages, the line can be the more easily recovered. Bench-marks are established every ½ mile. Borings are also made, if necessary, in larger river-beds.

Where the country is flat and there are no engineering reasons to the contrary, the lines, unless unduly lengthened thereby, are run through crown lands, in order to save purchase and cost of severance, though the latter has become insignificant in the more recent light lines, on account of fencing being dispensed with. The object of increasing the value of adjacent crown lands is also kept in view by projecting lines and fixing stations as near to them as is consistent with other requirements.

The field work having been finished and plotted, partly during wet days in camp, the estimate is then made, and, the Railway Commissioners' report being obtained, the project is ready for Parliament. The operations up to this point were formerly of a much rougher character than has obtained during recent years, much more being formerly left to the later final or permanent staking. This alteration is partly due to the greater attention now paid to location, which necessitates more care in the preliminary stages, having in view the nature of the expected traffic, practicable gradients against the direction of heavier loading, &c. It is also due to the greater demand for more accurate estimates as a basis for Parliament in adjudicating on the advisability of the proposed work. These considerations are taken to be stronger than the drawback of comparatively high expenditure in the preliminary stages of a project which may ultimately be rejected.

Under these circumstances, the permanent staking which, as a rule, follows acceptance by Parliament, and which is carried out

by the same means as the earlier survey, is reduced to little more than the mechanical operation of putting in and levelling and check levelling the chain pegs, though occasionally small variations in alignment, owing to modifications in the sites of stations, which have to be approved by the Railway Commissioners, agreements with land-owners, &c., are necessary. Trial pits are also now sunk to assist contractors in tendering. The plans and sections of the permanently-staked lines are photo-lithographed and bound in book form and the preparation of a revised estimate in view of letting the work by contract completes the operations. There are no fixed rules as to limiting gradients and curves, which vary according to the nature of the country to be traversed, and the direction and amount of the traffic to be dealt with. For short branch lines to partly agricultural districts, actual or possible, 1 in 40 to 1 in 60 gradients, and 10-chain curves, where unavoidable except by heavy works, are not unusual, and on these 1 in 60 against the loaded up traffic, and 1 in 40 against the lighter traffic from the sea-port, represent about equal gross traction. The great bulk of the up traffic of the colony, except for coal, which is dealt with by the old lines nearer the coast, is of low specific gravity, such as wool, live stock, hay and chaff, skins, &c., and as the population of districts producing these commodities is necessarily scanty, and the supplies to them form the bulk of the return down loading, the proportion between the up and down grading remains much the same as in the heavier grain-carrying lines with their larger population. Special attention has therefore to be given to this balancing of resistances, where the ruling gradient is required, so as to ensure that the full engine power necessary to take the partially loaded trains one way will be utilized in returning with the fully loaded trains in the reverse direction. On main connections, or deviations of old main lines, 1 in 80 against the up traffic, and 1 in 55 *vice versâ*, are generally aimed at, with 15-chain curves, while in the longer western lines across the plains, where traffic is most economically taken in long but infrequent trains, 1 in 100 is generally obtainable as a surface line. In these latter especially, but generally in all but the suburban lines, the number of passengers is comparatively so insignificant that goods traffic is the guide in these matters.

The tendency is, on main lines in New South Wales, notwithstanding the great reduction of train-mileage by the introduction of some of the most powerful locomotives in existence, to reduce it still further by cutting down the gradients of the old lines, and

projecting easy grading on the new lines. The same tendency, partially for a different reason, is noticeable in the case of proposed short branches, where comparatively easy grading is required to utilize, in their service, the weaker old engines which are being gradually cast from the heavy traffic of the main lines. The frequent employment of curves as sharp as 10 chains radius, to economize construction as against greater wear and tear to rails and rolling stock, principally in tires, is a question which has properly received much consideration. It is really all a matter of extent of traffic. Many of the branch lines of New South Wales have no greater traffic, nor is there any likelihood of its increasing much for many years, than that represented by 1,000 to 2,000 train-miles per open mile per annum. When it is considered that the total cost of rolling stock repair and renewals is only about 8*d.* per train-mile, or say £45 per open mile per annum on an average branch, and only a small fraction of this is affected even if the whole length be sharply curved, it is easy to see that sharp curvature, to save a very moderate amount of construction, is amply justified on such lines. The wear of rails is also insignificant in these cases. It is a very different matter where main lines or connections are concerned, with their much larger traffic.

All curves of lesser radius than 20 chains have transition, or easing, curves connecting them with the adjoining straight. Vertical curves are also used at summits and sags in the section. This eases the strain on the drawbars and buffer springs, and diminishes the wear of rolling stock generally.

Care is taken also that unnecessary losses of level in long ascents are not incurred, and the cost of working them is set against the saving in construction which might be gained by their adoption. 0·40*d.* per 1,000 foot-tons is a fair average extra cost of working such ascents in New South Wales, this representing roughly the extra amount of fuel and water used in rising over a given height, with an ordinary goods train, in addition to that expended on a level line of the same length, extra wear and tear to rolling stock being also included.

Another precaution adopted is that the ruling gradient and the sharpest curve on any line, or division of a line between engine-stations, is avoided through long tunnels, as otherwise, through the loss of adhesion, the severity of the ruling gradient would be practically increased. Level benches in long gradients are also introduced.

The cost of running train-mileage, that is to say, the wages of

trains' crew, the cost of fuel, water, and stores, the wear and tear of rolling stock, and maintenance of road only, but excluding general superintendence and station expenses, which are not generally affected, is an item which has constantly to be considered in testing the value of alternate projects. This is estimated to vary in the colony, according to local circumstances, between 2*s.* and 2*s.* 6*d.* per train-mile.

The scales generally adopted, both in trial and permanent surveys, are 4 chains to 1 inch horizontal, and 40 feet to 1 inch vertical; but in the long flat western lines, where the length of plans would otherwise be excessive, 10 chains to 1 inch horizontal and 100 feet to 1 inch vertical, are found to be sufficient for the trial lines. For city and suburban work the ordinary scales are doubled to 2 chains and 20 feet in the permanent staking. Cross-sections are plotted to 20 feet to 1 inch natural scale. A uniform datum [1] (100 feet below high water spring tides at Sydney) is adopted, and continuous through mileage from the two main ports, Sydney and Newcastle, is always used.

Since 1890, the survey work executed amounts to about 5,450 miles, and estimates have been made, in the same period, to the extent of about £38,000,000; but the extent of the latter work has diminished, relatively, the labour in connection with it, as innumerable examples and constants are tabulated and are available for successive estimates; and the practice of dealing with so large a number, and of such great variety, has so trained those concerned with them, that almost by the mere inspection of a section, an estimate might be made, fairly approximately, to within £200 or £300 per mile.

A large staff of engineers, surveyors, and draughtsmen are employed at this subdivision of the railway construction branch, averaging from thirty to sixty in number from time to time, according to the extent of the operations. Formerly, surveyors alone were employed at this work in the field, and a separate engineering staff was allotted to construction work proper, but for some years past, though the officers are still under separate subordinate control, the staff is interchangeable, with great advantage to the railway surveys, as no qualification is so valuable, in the execution of such work, as practical experience on construction. As a general rule, it is found that about the same

[1] At time of writing a conference is sitting, under the presidency of the Government Astronomer, to fix a common datum for all the State departments using one, and it is probable that mean sea-level, as less variable, will be adopted for that purpose.

number of draughtsmen in the head office as there are surveyors in the field are required.

The engineers and surveyors, in addition to salary, receive a fixed allowance, when in the field only, which is calculated to cover all the expenses in connection with the work, such as provision and maintenance of tents, and other equipment for themselves and their men, three horses, vehicles, and carts, and instruments. This allowance is at the rate of £180 per annum, but fixed additions are made for the more westerly districts of the colony, which are defined, where cost of forage and other expenses are heavier. In city or suburban surveys, where instruments only are maintained, allowances at the rate of £40 per annum are given.

The cost of field work of surveys has varied greatly according to the ability of the surveyor, the nature of the country, thickness of forest, climate, weather, &c. That of trial surveys ranges from about £8 per mile in the flat country, with otherwise favourable circumstances, which do not often come together, to £70 to £80 where the country is heavy, or where there are other obstacles to progress. Permanent staking in the country has not generally such a great range, and has never been carried out for less than £15 per mile. A short close town survey, however, which was also through hilly ground, has cost as much as £340 per mile. The cost per month of each camp, including salaries, averages about £85.

These railway surveys of New South Wales have been, for the last six years, under the immediate superintendence of the Author, acting under Mr. H. Deane, M.A., M. Inst. C.E., Engineer-in-Chief for railway construction, the features more particularly described in this Paper occurring within that period.

The Paper is accompanied by four tracings, from which the *Figs.* in the text have been prepared.

(*Paper No. 3072.*)

"Automatic Inclines and Railway, Junin, Chile."

By Josiah Harding, M. Inst. C.E.

The greater part of the nitrate of soda exported from the province of Tarapacá, in Chile, is found in beds along the edge of the Tamarugal plain. The nitrate beds are generally about 1,000 metres above the sea-level, and are separated from the coast by ranges of hills running generally north and south, *i.e.*, parallel with the coast. The coast range itself becomes in many places a plateau between 2,000 feet and 3,300 feet high, with a precipitate descent to the sea and comparatively level inland. The nitrate railways were constructed to work these beds, or to carry the nitrate produced from them, connecting them with the ports of Iquique and Pisagua. With the object of obtaining a more direct and a cheaper communication with the coast, from some of the more centrally-situated grounds, the Agua Santa Railway and inclines were constructed from the designs of the late Mr. James Handley. The inclines were necessary to connect the port (Caleta Buena) with the plateau, here more than 2,000 feet above sea-level, the face of the hill being very steep. At Caleta Buena the incline is divided into three sections, the railway wagons being passed from one to the other over level stations.

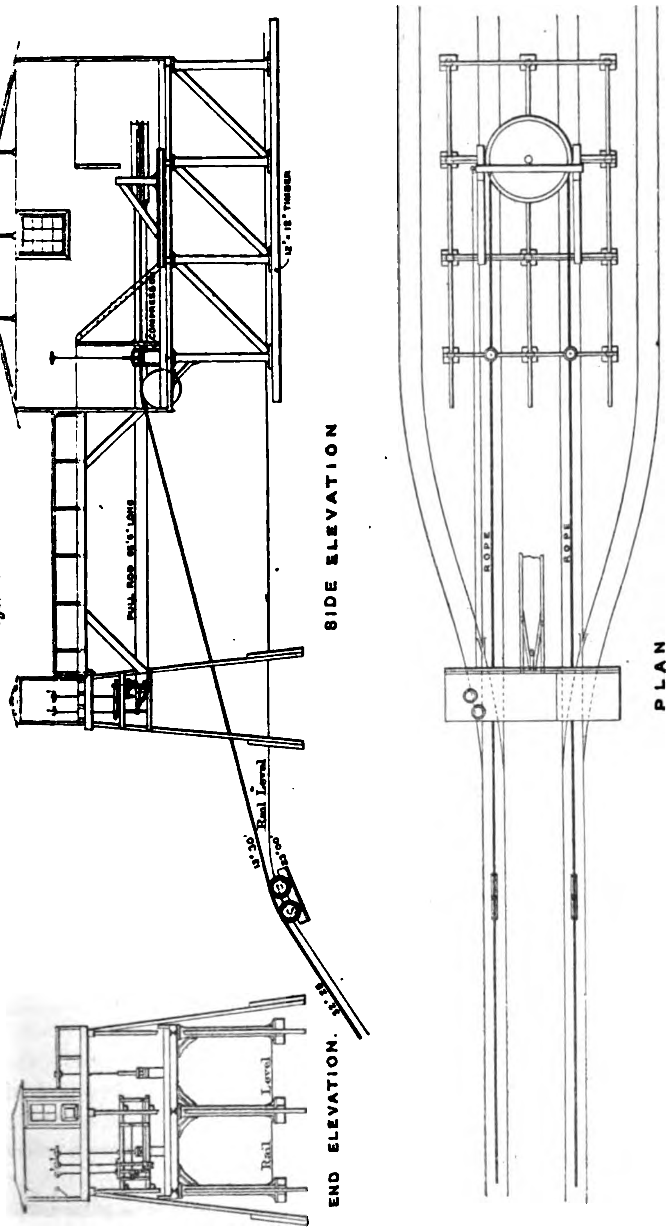
In May, 1892, the Author was called in to examine the proposed inclines and railway from the port of Junin. He found that at the most suitable place for the incline the ground rose from the sea to a height of 2,237 feet, with an average inclination of over 50 per cent. to the plateau or Alto de Junin, whence he found that a railway with a maximum gradient of 3 per cent. could be constructed to pass the intervening ranges and reach the nitrate grounds of Sal de Obispo with a summit-level of 3,510 feet above sea-level, or 230 feet above the plains of Sal de Obispo.

First Incline.—The most important portion of the work was the system of inclines to connect the port with the plateau or Alto. In view of the favourable slope of the hill, the Author proposed to make a single incline from top to bottom, but this idea met

with so much opposition from those who had gained experience in working the inclines at Caleta Buena, that it was decided to construct the incline in two sections, with a changing station near the middle, the more so as the machinery and ropes had already been ordered for an incline in two parts. Owing to the nearly uniform steepness of the hill, it was difficult to obtain sufficient flat for the central station. By cutting into the hill to steepen the upper section, and embanking the upper part of the lower section, sufficient space to change the wagons on the level was obtained, the embankment running far down the lower incline owing to the fact that the slope of the hill approached very nearly to the natural slope of the material. The inclines were worked with Craddock plough-steel ropes, 1 inch in diameter, made on the Lang lay. The ropes pass around horizontal Fowler clip-drums, 7 feet in diameter. The wagons are attached, one at each end of the rope, the descending wagons loaded with nitrate of soda, weighing about 9 tons, and the ascending wagons with coal, fodder, merchandise, &c., being generally about one-half the weight. The speed is controlled by two strap-brakes to each machine, and a compressor to grip the ascending part of the rope as the wagon comes over the brow so as to prevent its slipping round the drum. The rope is carried on wooden rollers, about 6 inches in diameter, and about 30 feet to 45 feet apart, with cast-iron pulleys, 18 inches in diameter, at the head of the inclines. The rails are laid in a double line, separating into four lines at the top and bottom and at the central station. The switches at the central station are laid on the inclines. Work was commenced in July, 1892, and the traffic was begun in January, 1893, although the construction was not quite finished.

Second Incline.—As the traffic increased it soon became apparent that a second incline was required, and a careful study of the working of the first convinced the Author that many improvements might be introduced. In the first place he decided to make the incline in one length. In laying out the gradients, it was desired, as far as possible, to balance the weight of the rope by the steepness without incurring too heavy expense in cuttings, &c. The perfect realization of this would be a parabolic section, the upper end being about 12° steeper than the lower end. As this was not practicable in the present case, the upper end being flatter than desirable, the lower end was correspondingly flattened also. In practice it is found that the wagons will start with very nearly equal facility on any part of the incline. The vertical height of the incline is 2,214 feet, and the length 4,084 feet,

Figs. 1.



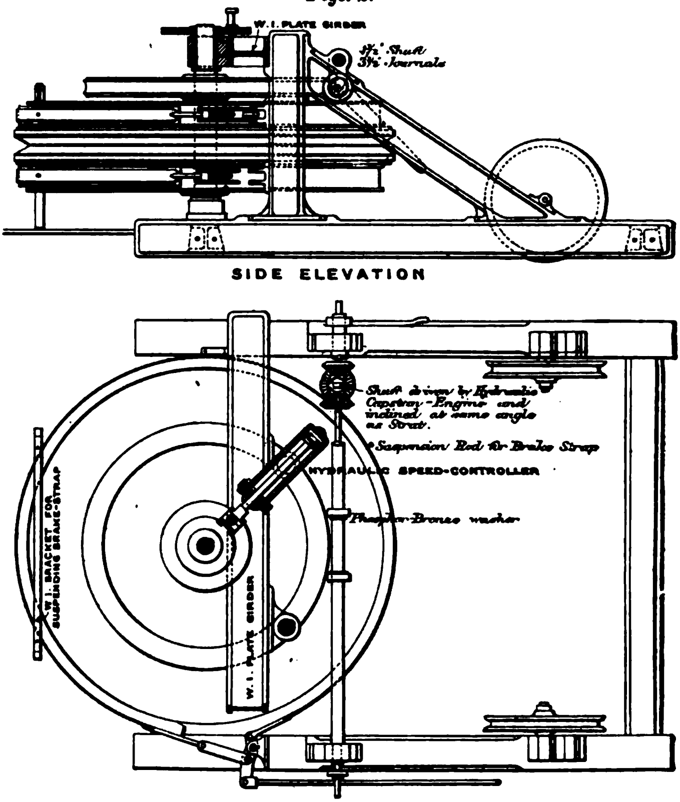
PLAN

Scale, 1 inch = 24 feet.

JUNIN INCLINE NO. 2.—GENERAL ARRANGEMENT AT THE HEAD.

the average gradient being over 54 per cent. The inclination is 22° 30′ at the lower end and 32° 28′ (since increased to 34°) at the upper end. The maximum inclination is 37° 09′. The incline crosses the zigzag cart-road twice, by means of wooden bridges. The material in the cuttings was principally granitic rock, much

Figs. 2.



Scale, $\frac{3}{16}$ inch = 1 foot.

BRAKE MACHINE.—JUNIN INCLINE No. 2.

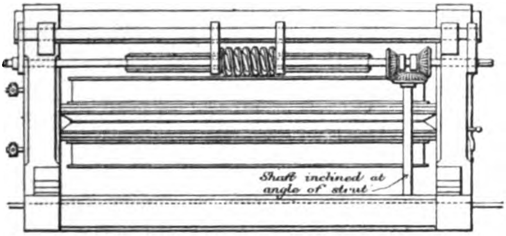
cracked and decomposed. The two lines of rail are laid at 10 feet centres and branch into four lines above and below. On the steepest part of the incline stakes are driven below the sleepers to prevent their slipping down the hill.

The brake machine at the head of the incline was raised upon a framework of braced columns and girders, *Figs. 1*, so as to allow the

wagons to pass underneath, and give a better line for the rails. There is a clear headway of 12 feet over the rails.

Brake Machine.—Considerable alteration was made in the design of the machine for the first incline. The diameter of the Fowler

Fig. 3.



END ELEVATION

Scale, $\frac{3}{16}$ inch = 1 foot.

BRAKE MACHINE.—JUNIN INCLINE No. 2.

clip-drum was increased to 10 feet and two brake-drums were bolted directly to it, one above and one below, *Figs. 2* and *3*. The strap-brakes are applied by vertical screws, placed so as to give a good view of the whole incline. The screws are connected by bell-cranks and pull-rods with the levers of the strap-brakes. Inside the rims of the brake-drums pockets are provided for water to keep the drums cool. Screw compressors are also placed to hold the slack of the rope when the wagon arrives at the top. They are applied to the ascending rope only. The compressors are formed of blocks of wood on end set in frames, one fixed below, and one attached to the screw above the rope. Above the clip-drum there is a worm-wheel, the worm being arranged to be thrown in and out of gear. It is driven by a hydraulic engine for the purpose of pulling the descending wagons over the head of the incline. The worm is then thrown out of gear and the wagon is run down on the brake.

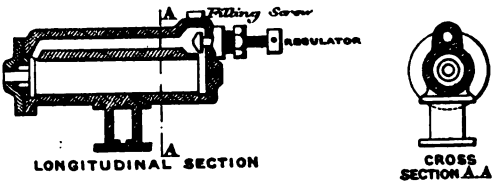
Hydraulic Controllers.—Two closed oscillating cylinders, *Figs. 4*, were provided to act as speed controllers, but the irregularity of the resistance caused excessive vibration, and they were therefore disconnected. Had the piston-rods been carried through the back covers of the cylinders, the resistance would have been more uniform.

Pulleys and Rollers.—The rope is carried on one 5-foot pulley in the machine-room, two 30-inch steel pulleys at the head of the incline, and one at the point where the gradient steepens; and on cast-steel rollers, at distances averaging about 33 feet, on the

whole length of the incline. These rollers are steel castings 12 inches in diameter by 12 inches long, made very light, the rims being only $\frac{3}{8}$ inch thick. The journals are cast on, being joined to the rims by five curved spokes at each end. The rollers run in cast-iron bearings attached to the sleepers. The line was first laid with hard-wood rollers, but the change to the steel rollers has been a great improvement, both in economy and in the reduction of friction, which has been so great as to enable nearly double the up-load to be carried.

Ropes.—Craddock plough-steel ropes $1\frac{1}{4}$ inch in diameter are used on this incline. The life of the ropes is variable, between 1 year to more than 2 years. They do not wear out in the ordinary sense of the term, but fail by the breakage of the wires. When the wires begin to break very frequently, it is regarded as evidence that the rope is unsafe and it is changed. An Elliot locked-coil rope $1\frac{1}{8}$ inch in diameter was tried, and it at first gave

Figs. 4.



Scale, $\frac{3}{4}$ inch = 1 foot.

HYDRAULIC SPEED CONTROLLER.

promise of success; but, after 6 months' work, the wires near the ends of the rope bulged like a bird-cage and became unlocked. This was evidently caused by the outer wires being more stretched than the inner wires, and as the rope passes through the compressors the slack of these wires is forced towards the ends of the rope. This would imply that, excepting when the rope is quite new, the outer coil of wires bears no part of the strain near the ends of the rope.

Permanent Way.—The gauge of the railway is 2 feet 6 inches, and the rails weigh 36 lbs. per yard. The fish-plates are of a deep pattern, and, as the lower flanges of the fish-plates butt against the sleepers, the rails are effectually prevented from creeping. The railway wagons, which also run on the incline, are of the four-wheeled pattern, 10 feet long by 6 feet 6 inches inside, and weigh about $2\frac{1}{4}$ tons empty; they carry $7\frac{1}{2}$ tons of nitrate of soda. The wagons have spring buffers at each end, and on the railway

are coupled together with the Norwegian hook. On the incline they are attached to the rope by the ordinary coupling pins at each end, the rope passing under the body of the wagon with a ring and links inserted in such a position that an approximately equal strain is applied at each end. The usual time occupied in ascending or descending is about 3½ minutes, an average speed of about 13½ miles per hour. The ordinary downward load is about 7 tons and the upward about 4 tons, when there is sufficient upward cargo to give it; but the average upward cargo does not exceed 30 per cent. of the downward cargo. The heaviest load ever taken up the incline consisted of the frame and cylinders of a locomotive, weighing 10 tons, or 12 tons with the wagon on which it was carried; two wagons of nitrate, weighing 16 tons, being run down.

The upper and lower offices are connected by telephone and by an electric single-stroke gong to signal the brakesman when to start or stop. At the Alto, or on the plateau at the head of the incline, the railway workshops and offices are situated. The most distant nitrate oficina is 30 miles from the Alto. At Sal de Obispo, 19 miles, are the wells and pumping-station for supplying the line and establishments with water. The water, of fair quality, is pumped from wells about 49 feet deep into tanks at the summit, 6 miles distant and 70 metres above the ground at Sal de Obispo. Thence the water flows through pipes, 2 inches in diameter, to the Alto, where the pressure is sufficient to drive an electric-lighting plant, consisting of a Pelton motor coupled direct to a small dynamo, running at 1,200 revolutions per minute, and lights about forty 16-candle-power lamps. In the daytime the pressure drives the hydraulic engine for starting the wagons on to the incline, and also some hydraulic capstans. The water is discharged from the machines into tanks for the supply of the locomotives and establishment, the surplus passing down the incline to the port, where, after working the cranes on the piers, &c., it is discharged into tanks for the supply of the inhabitants and shipping. The pressure available from the Alto to the port is about 950 lbs. per square inch. The pipes are all of lap-welded steel, with loose flanges and male and female joints, lead rings being inserted between the flanges.

Cost.—It will be interesting to compare the original cost and working expenses of this incline with that of a railway between the port and Alto, having a maximum gradient of 1 in 33. The result of surveys shows that it would require 15½ miles of railway, costing, with rolling stock, &c., £50,000. The cost of the incline

with one rope was £9,000. The cost of working the railway, including handling the wagons below only with mules, is shown by the Appendix to be 10·65*d.* per ton. The cost for the incline is only 3·44*d.* per ton, including handling the wagons both above and below. If interest be added, say, 8 per cent. on £50,000 for the railway (4*d.*), or on £9,000 for the incline (0·72*d.*), the total cost for the railway is 14·65*d.*, and for the incline 4·16*d.* per ton of freight.

The working costs of the present incline, together with estimates of the cost of working the ideal railway and incline, taken from the expenses on the Junin railway with similar gradients, are shown in the Appendix. The amount of freight carried in each case is assumed to be seventy-five wagons per day up and down, with a load of 80 Spanish quintals up and 155 Spanish quintals down, making a total freight, for the year of 300 days, of 5,287,500 Spanish quintals, or 240,341 tons.

The Paper is accompanied by three tracings, from which the *Figs.* in the text have been prepared.

APPENDIX.

Table I.—Junin Incline. Cost of Working Twenty-five Wagons Up and Down Daily for One Year of 300 Days.

	£	s.	d.
Renewals (rails, sleepers, &c.)	33	0	0
Rollers	127	12	6
Brakes, painting, &c.	112	10	0
Workshop's account	225	0	0
1½-inch steel rope (average life 18 months)	348	15	0
Clerks and overseers	445	0	0
Brakesmen and assistants (twelve in all)	1,161	0	0
Mule boys	270	0	0
Maintenance of mules, &c.	279	0	0
Errand boy	54	0	0
Water power[1]	270	0	0
Oil and sundries	123	7	6
	3,449	5	0

On 240,341 tons = 3·44*d.* per ton.

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[1] This item is profit for the water account, as the water is all passed into the tanks after passing through the machines.

TABLE II.—ESTIMATED COST OF TRAFFIC ON 15½ MILES OF RAILWAY, WITH A MAXIMUM GRADIENT OF 1 IN 33, TO REPLACE THE INCLINE BETWEEN THE PORT OF JUNIN AND THE ALTO.

The traffic indicated would require:—

	Per Month.					Per Annum.	
	£	s.		£	s.	£	s.
Three engines daily, with three drivers	22	10	=	67	10		
Three firemen	11	5	=	33	15		
Three conductors	9	0	=	27	0		
Nine brakesmen	6	15	=	60	15		
				189	0		
						2,268	0
Six cleaners						540	0
One lighter-up, &c.						108	0
Coal = 1,000 tons at £1 13s. 3d.						1,650	0
Water, 28,880,000 gallons at 0·09d.						1,080	0
Oil waste, &c. = £9 per month each engine						324	0
Repairs of engines						1,800	0
Three pointsmen at $90 per month each						243	0
One stationmaster						135	0
Telephone						216	0
Permanent way (labour)						1,593	0
„ „ (materials)						112	10
Repairs of wagons						187	10
Oil and waste for wagons						136	0
Mule boys and maintenance of mules						274	10
						10,667	10

On 240,341 tons freight = 10·65d. per ton.

(*Paper No. 3081.*)

"Railway Construction through Bog-Land."

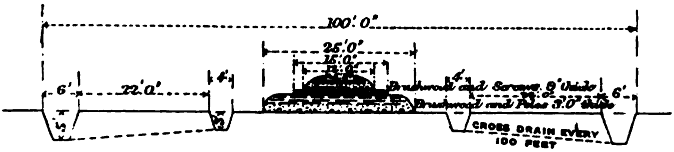
By Richard Joseph Howley, Assoc. M. Inst. C.E.

The Galway and Clifden Railway, a line of standard Irish gauge, extending from the Galway terminus of the Midland Great Western Railway to Clifden, is the longest of the railways towards the construction of which, in the poorer districts of Ireland, the Government made numerous grants in 1890, its total length being about 48 miles. The route followed passes through the wild region of Connemara, a district covered with large tracts of uncultivated bog, and broken by steep rocky mountains, the slopes of which are destitute of the scantiest vegetation. The rock belongs principally to the schistose group, and is largely intersected by granite veins. It is most difficult to excavate, owing to its brittle character, and heavy cuttings had to be avoided as much as possible. The route followed lay, therefore, more through the low-lying bog-land than would otherwise seem necessary. Of the total length, about one-half has been constructed on a peaty surface, varying widely in character, between soft water-logged mud and firm well-drained turf. The bogs, which are of the red variety common in Ireland, vary in depth between a few feet and 50 feet, and are generally separated from the underlying rock by a thin layer of clay, often containing shells and other evidences of an ancient lake bottom.

In locating the line, the extent and impassability of some of the bogs caused much trouble; one of those passed through—Maam Bog—having an extent of about 10 square miles, unbroken by fences or other traceable landmarks. Another—Glengowla Bog—which, when drained, carried an excellent road, could only be crossed on foot at great personal risk. In determining the suitability of a bog to safely carry a railway line, the principal point to be noticed is its position in regard to future drainage. If a bog is so placed that the side drains, by well-situated and frequent outfalls having sufficient fall, can be kept free of

water, then little difficulty will be experienced in the construction of the line. But if, on the other hand, the bog lies, as is often the case, in a large basin formed by the underlying rock, or little above the level of a neighbouring river or lake, the provision of adequate and efficient outfall drains may be impossible, and the construction of the line will be a work of difficulty and uncertainty, and the future maintenance will only be carried out by constant care and expense. The minimum cross-section adopted for the bog-formation on the Galway and Clifden Railway is shown in *Fig. 1*. The width of land taken was very great. It must, however, be remembered that the price of bog in Connemara is very low—one large proprietor giving the land for many miles free of cost. For the thorough drainage of the line two rows

Fig. 1.



Scale, 1 inch = 32 feet.

MINIMUM CROSS-SECTION GALWAY AND CLIFDEN RAILWAY.

of longitudinal drains are necessary, the inner pair to drain the line proper, the outer pair to intercept the drainage of the surrounding bog.

The porosity of these Galway bogs is remarkable; the surface in places contained so much water that it sank 10 feet when the peat had been drained. A couple of years after the drains for the railway had been cut in Maam Bog, the line in parts seemed to lie in a hollow, the ground rising gradually from the outer pair of drains. This depression was altogether due to the shrinkage of the peat after being drained, the surface having been originally horizontal. The drainage is very slow; 2 years is about the time the surface peat takes to dry after the drains are in working order.

The two pairs of longitudinal drains are placed 22 feet apart, and are connected together by cross-drains every 100 feet. The inner drains were cut at a distnace of about 6 feet from the toe of the embankment; they were 4 feet wide at the top and 3 feet deep. The outer drains were 6 feet wide by 5 feet deep. The cross-drains were 12 inches wide at the bottom, and had a slight fall towards the outer drains. The side slope of all these drains

was 1 in 3. In some cases cross-drains were cut every 25 feet from the inner longitudinal drains towards the centre-line, to hasten the drying of the surface.

For a year at least all these drains, both longitudinal and cross, require a great deal of care, as at first a fine peaty mud comes through the sides and bottom, which, if not removed, would quickly render them useless. The expense of this is not heavy, as the original section of the drain remains unaltered, and the blocking material is easy of removal. This complete drainage of the site would appear tedious, but it consolidates and preserves the original surface, and renders it capable of bearing an embankment, the weight of which is distributed over a large area. Should the surface not be properly consolidated by drainage, it is apt to give way under the weight, and the filling of these breaks is very troublesome and expensive.

The surface of a bog is composed of matted vegetable matter, coarse grass, heather, &c. If this skin is not disturbed it will carry a considerable weight without breaking, so that the preservation of the sod intact, and the lessening of the weight on it, are matters of great importance. The ideal section would, therefore, be a surface line, or one with about 2 feet of embankment, which could be made from the material excavated from the side drains. So careful are some engineers to prevent any injury to the surface that they will not allow the lockspitting of the centre line over bogs.

Several methods of constructing the embankment on bog formation were tried on the Galway and Clifden Railway:—(1) With brushwood and poles underneath and brushwood and scraws, *i.e.*, thick sods, on the top. (2) With brushwood and poles only under the bank. (3) The bank constructed of turf and clayed over, no brushwood being used.

In the first method brushwood, poles, and tree-tops were spread for a depth of 3 feet over the surface to be covered by the bank, the lower 18 inches being laid longitudinally and the upper 18 inches transversely. The peat embankment was then made on this, and was covered on the top for a width of 15 feet with a thin layer of brushwood and scraws, over which the ballast was spread. This method was soon discontinued. Great difficulty was experienced in obtaining suitable poles and tree-tops, as plantations were noticeable in Connemara by their absence. It was also found that the brushwood on the top was not needed when the peat was clayed over, and peat embankments without a covering of clay were not successful, the water getting

into the peat and keeping it soft. A very large allowance for subsidence had to be made in this type of embankment.

The second method, where only the 3 feet of brushwood under the bank was used, was more successful, especially in those cases where clay was used. It distributed the weight and saved the surface from being broken, the clay banks not having the spring of those constructed of peat. In tipping the clay on to the brushwood two tip-heads should be used, one on each edge of the brushwood, as, if there is but one, all the weight coming on the centre of the brushwood makes the sides tilt up and form a cleaving edge under the centre of the embankment, doing more harm than good.

The third method, where the embankment was constructed wholly of peat and afterwards clayed over, no brushwood being used, was found by far the most satisfactory and economical. It was the outcome of experience gained in constructing the first few peat embankments, and afterwards almost wholly superseded the other methods. The embankment is constructed of peat, excavated from the side drains, and scraws taken from the surface of the bog lying between the inner and outer longitudinal drains. It should be finished in summer, so that when the clay covering is run on the peat is nearly dry and quite elastic. The clay covering, which should be run on before the winter's rain has soaked the peat, generally consisted of the stiff marly clay which underlies the bogs, and shows up round the edges. It is most suitable for the purpose, as on exposure to the air it hardens quickly and forms a waterproof covering. The depth to which the peat was covered averaged about 18 inches; it was run on in small tip-wagons drawn by a light engine running on a 3-foot road. On the bog sections where the clay covering was used the bottom ballast consisted of round stones, as the hand-packed soling used on the other sections would quickly have cut through the clay covering. Some of the worst bogs were treated in this manner, which was found very successful. The principal point to be observed was to have the peat covered before it had become sodden by the winter rains, when it became a great deal less elastic and lost much of its carrying power.

The method adopted in carrying the line through a peat cutting shows the importance of leaving the crust of the bog intact. The only successful method was to excavate the peat below formation for a couple of feet and to tip in clay to form a surface of sufficient strength to carry the road. A quantity of clay equal to twice that of peat excavated had to be tipped in before subsidence

ceased, so that peat cuttings were expensive, peat excavation and clay filling having both to be paid for. In cases where the hard rock or clay was close to the formation all the peat down to it was excavated.

Although, as a rule, the bogs afforded a good carrying surface, there were parts, especially those which could not be properly drained, where, for some time after the contractor's engines were at work over them, the surface used to collapse in places and the embankment sink, sometimes 6 feet or 7 feet in the course of an hour. The brushwood, originally horizontal, might then often be seen standing vertical at each side like a fence. When these subsidences occurred in the softer bogs the bank had to be made up with rock. Clay was not heavy enough, and spread out in the semi-liquid peat. It was found that after three or four times the estimated amount of clay had been tipped in it would often appear at some crack 30 yards or 40 yards from the centre-line. In such cases the wagons containing stone would be run into the hollow, and, after being emptied, would be hauled out by means of a wire rope attached to the engine; it was not considered safe for the latter to approach too near the break.

The line was laid with flat-bottomed rails, weighing 65 lbs. to the yard. On one of the larger bogs the Midland Great Western main-line rail of 79 lbs. was used with advantage, more evenly distributing the weight and making a stiffer road. A three-wire fence was used on the bog sections, with larch posts 9 feet apart, placed inside the outer drains. Peat makes a bad mound, as the sods dry and never bind together.

The maintenance of a bog line will always be somewhat higher than one constructed on more solid ground. In cases where the surface has not been broken through in many places the difference will not be great, and, owing to the elasticity of the road, a saving in wear and tear of permanent way and rolling stock may be counted on. In laying out a line alternate short lengths of peat and rock should be avoided. It was found, in running along a rocky hillside, that the junction between the hard and soft was very marked, the road becoming irregular and unpleasant to travel over unless constantly attended to.

Foundations for culverts, where they occur in any depth of peat, often form a heavy item. Difficulty was in some cases experienced in obtaining suitable water for mixing the cement-mortar and concrete, the peaty liquid of the bog drains acting very injuriously on the cement. In concrete foundations it was found that the outer 6 inches was generally rendered useless by the

action of the bog water. On the other hand, the preserving power of the peat on timber was shown in several instances by the soundness of ancient tree-roots and limbs excavated, and suggests the great suitability of timber barrel or box drains instead of masonry culverts.

Since the line has been opened for traffic the Midland Great Western Railway have been running some of their heaviest engines and rolling-stock over it, and the bogs have stood the strain perfectly; in fact, they form by far the pleasantest portion to travel over, the spring rendering the motion very easy.

The Paper is accompanied by a tracing, from which the *Fig.* in the text has been prepared.

(*Paper No. 3017.*)

"Simla Waterworks."

By Charles Ernest Vere Goument, Assoc. M. Inst. C.E.

Simla, the summer head-quarters of the Government of India, is situated in the North-West Himalayas, at a mean elevation of 7,200 feet above sea-level. It contains in summer a population of 25,000, of which about 3,000 are Europeans. The winter population is much smaller, as most of the Government offices move down to Calcutta for the winter months, November to March.

Until the year 1879–80 its water-supply was dependent on springs in the station itself, the yield of which was very uncertain, and the quality of the water was not satisfactory, as the springs were liable to contamination from the drainage of houses above them. The Municipality therefore decided to bring water to the station from four perennial springs in the Mahasu forest, about 11 miles above Simla. This project was carried out in 1880 by Mr. F. J. Johnstone, M. Inst. C.E., executive engineer, and Mr. B. Parkes, B.C.E., Assoc. M. Inst. C.E., assistant engineer. The supply secured was 225,000 gallons a day for 9 months of the year, and 100,000 gallons daily during the three hot months, April to June. Its total cost in round numbers was Rs.10,00,000, or about £70,000.

The entire catchment-area above the springs has been acquired by the Municipality and is strictly preserved. The water is passed through small filter-beds of sand and gravel at the springs, and is conveyed to Simla by gravitation in a 6-inch cast-iron main, laid along an accommodation road cut in the hillside at a gradient of 1 in 300. The full discharging capacity of this main is 225,000 gallons in 24 hours. This quantity is available for 9 months of the year, but the springs yield only 70,000 gallons a day in the three hot months. Two storage-reservoirs, with a total capacity of 3,000,000 gallons, have been constructed in the station to supplement the hot-weather supply. These reservoirs contribute 34,000 gallons a day for 3 months, and increase the total supply in these months to 100,000 gallons a day. Their cost was approximately Rs.7,00,000. The distribution is effected through

cast-iron pipes 5 inches to 3 inches in diameter, and stand-posts and fire-hydrants are fixed at convenient points on all the main roads of the station.

Shortly after the works were opened, it was found that the hot-weather supply was inadequate to meet the wants of the summer population, and it was decided to carry out extension works to increase the supply during the hot months to 240,000 gallons per day, or 8 gallons a head for a prospective population of 30,000. In 1890, Mr. A. Younghusband, assistant engineer, was deputed to investigate all the likely sources of supply in the neighbouring hills, and he proposed to pump the additional supply required from the Cherot stream, which runs at the base of the same range of hills from which the former supply is drawn, the supply to be taken at a point 1,200 feet below the storage-reservoirs and about 5 miles from Simla. This proposal was accepted, and a scheme was drawn up by the Municipality in 1891 for the construction of the necessary works. It did not, however, meet with the approval of Government, and was not sanctioned. The Author took charge of the works in 1892 and prepared the revised scheme described in this Paper. The extension works cost Rs.3,80,000, inclusive of all charges, and their annual working expenses are 4,500 rupees for 3 months' pumping. The average daily supply obtained is 130,000 gallons. The works were commenced July 1892, and opened April 1893. The Author held charge during the whole period of their construction.

THE NEW WORKS.

The works consist of a separating-weir in the bed of the Cherot stream, Fig. 1, Plate 5 (which catches the clear dry-weather flow and rejects dirty flood-water), filter-beds, pumping-station and clear-water reservoir, pumping machinery, rising-mains and gravitation-main.

Catchment-Area.—The entire area which forms the gathering ground of the stream has been acquired by the Simla Municipality, and is strictly preserved to preclude all possibility of contamination. The greater part of this area is already under forest, chiefly deodar (*cedrus deodara*), and the bare parts are now being planted out. The area taken up is a valley about 1¼ mile long and 1 mile across, the difference of level between the bed of the stream at its lowest point and the surrounding watershed being about 1,500 feet.

Separating-Weir.—The weir, Figs. 3, Plate 5, is built across a narrow gorge on a bar of solid rock which brings all the water to

the surface and prevents any escape under the weir. The ends are built well into the rocky sides of the gorge and are water-tight. A 6-inch pipe carries the water from a duct or catch-pit in the body of the weir to the filters. The total cost of this weir was Rs.3,500 or about £200. The arrangement for admitting clear water and rejecting dirty flood-water is partly automatic and partly adjustable. If the dry-weather clear discharge of the stream had been constant, it would have been sufficient to form the opening into the weir so that the parabola described by the water when the discharge exceeded the limit of clear flow would fall beyond the opening, but this is not so. The dry-weather flow varies considerably from year to year, and depends entirely on the snowfall during the preceding winter. It follows, therefore, that the clear discharge of one year might be equal in volume to the dirty discharge of another year. This being the case, it has been necessary to provide an adjustable sliding-cover over the opening, which can be set by the attendant in charge from time to time to suit the discharge of the stream, Figs. 3. The loss of water in the dry season during floods when too dirty to take in is insignificant, as freshets at this time of the year are not frequent and, when they occur, they seldom last more than 2 hours or 3 hours. The minimum clear discharge of the stream is 120,000 gallons a day. The maximum clear discharge, which lasts for 2 days or 3 days only, after freshets, is 230,000 gallons in 24 hours.

Filters.—The filters, Figs. 4 and 5, Plate 5, are divided into three beds of equal area. Two only are used for filtering the ordinary supply of 130,000 gallons in 24 hours, while the three working together are capable of filtering the maximum clear discharge of an average season, viz., 230,000 gallons a day. As this maximum is only available for 2 days or 3 days after a freshet, the third is practically a spare bed and admits of the filters being cleaned periodically. A by-pass connects the inlet- and outlet-pipes, and water can, if necessary, be run direct from the weir to the pumps without entering the filters.

The filtering material consists of 2 feet of fine sand, 6 inches of coarse sand, 6 inches of fine gravel and 6 inches of coarse gravel, resting on bricks laid flat, with open spaces $\frac{3}{4}$ inch wide. These spaces form a system of narrow drains leading to the main drains in the concrete floor of the bed. The cross main drains measure 12 inches by 9 inches, and the longitudinal main drain running into the clear-water effluent-chamber 12 inches square. The necessary overflow-, emptying- and air-pipes have been provided, as shown in Figs. 4 and 5. The floors are of lime-mortar concrete

12 inches thick, and the walls are of uncoursed rubble-masonry in lime mortar, composed of 1 part hydraulic stone lime, and 1½ part of powdered brickdust. The floors and walls are plastered inside with Portland-cement plaster ⅜ inch thick, composed of 1 part of cement and 2 parts of sand.

The effluent-pipes from each of the filter-beds and the by-pass run into one line of 6-inch pipes, which conveys the filtered water across the bed of the stream to the feed-reservoir of the pumps. This line is laid about 8 feet below the bed on hard shale, and is embedded in concrete, 3 feet by 2 feet in cross section, along its entire length. At its lowest point on the south bank of the stream a scour-valve is provided in a chamber built to a height of 5 feet above highest flood-level.

The filters usually work under a head of 8 inches, the difference of water-level between the filters and the effluent or clear-water chambers. The rate of filtration under this head is 800 gallons per square yard in 24 hours, or 7 inches per hour.

Pumping Station and Clear-Water Reservoir.—The plan of this block of buildings, Figs. 6, Plate 5, was governed to a great extent by the outline of the rock foundation on which it stands, and the site was obtained with difficulty by cutting back the hillside to a depth of over 60 feet at its highest point. The engine- and boiler-rooms are, therefore, somewhat smaller than they might otherwise have been. The basement of the engine-room is utilized as a part of the clear-water reservoir, and is connected to the reservoir outside the engine-house by a 9-inch pipe. The reservoir is 12 feet deep, from overflow level, and has a total capacity of 130,000 gallons, which is somewhat over ½ day's maximum supply. This storage was necessary, as the engines pump only 12 hours a day while the filters work continuously.

The engines and pumps rest on solid blocks of masonry built up from the basement floor. The walls of the reservoir and the basement walls of the engine-room are of uncoursed rubble-masonry in lime mortar. The walls of the superstructure are of coursed rubble in lime mortar, and the floors of lime-mortar concrete. The inside of the reservoir is lined with Portland-cement plaster of the same description as that used for the filters. The engine-room is floored with glazed tiles set in cement. The chimney is 87 feet high. It rests on solid rock and is built of brickwork on a bed of concrete 2½ feet thick and 13 feet square.

Pumping-Engines and Boilers.—The engines are designed to pump in 12 hours the maximum daily clear discharge of an

average hot season. This has been estimated to be 230,000 gallons. The actual height to which the water is forced from the pumps is 1,255 feet. The head due to friction in the rising-mains (two steel tubes, 2,700 feet long and 5 inches in diameter) is 53 feet. The total head against the pumps is therefore 1,308 feet.

Two engines are provided, each to pump half the maximum supply in 12 hours or the whole in 24 hours. As the ordinary daily supply is only 130,000 gallons, or about one-half the maximum, one engine working 13 hours is equal to the ordinary demand, and the other engine is practically in reserve. The maximum supply, viz., 230,000 gallons, is only available for 1 day or 2 days after freshets in the dry season.

The engines are of the Worthington triple-expansion jet-condensing type, by Messrs. James Simpson and Company. They are designed for a working boiler-pressure of 100 lbs. per square inch and for a normal speed of steam-pistons and water-plungers of 120 feet a minute. They are each of 80 I.HP., and cost in England, with two Babcock-Wilcox boilers and a light overhead traveller, £3,990. Their cost erected complete in India was Rs.82,000. The total weight of the engines was 40 tons and that of the boilers 21 tons. The leading dimensions of the engines and pumps are as follows:—

	Inches in Diameter.	
High-pressure cylinder	$8\frac{1}{2}$	Stroke, 1 foot 6 inches.
Intermediate-pressure cylinder	13	
Low-pressure cylinder	$21\frac{1}{2}$	
Main-pump plunger	$4\frac{3}{4}$	

The main pumps are of the Worthington plunger-type, and are double acting on both the suction and delivery. The steam cylinders and valve-gear are of the ordinary Worthington type. There is no air-vessel on the pump delivery, as the pressure is 540 lbs. to the square inch, and it was considered that the absorption of air under this pressure would have been so rapid as to render the vessel almost impracticable. The pumps being duplex double acting and working against a fixed load, the delivery is very uniform, and no inconvenience is felt from the omission of the air-vessel. The pumps have spindle valves of Delta metal, working on metal seats against gun-metal springs. The two delivery mains are connected immediately beyond the pumps by a cross connection, Figs. 6, which enables either or both engines to be worked with either or both mains.

Owing to the high lift against which the engines work, the

condenser overflow bears an unusually large proportion to the total quantity of water pumped, about 33 per cent. It is run back to the feed-reservoir after passing through a separator, which removes all traces of any lubricating oil the steam may have taken up in its passage through the cylinders.

This separator is shown in Figs. 7. The overflow water is admitted at one end of the tank, near the top, and flows smoothly along the surface towards the waste-weir at the opposite end. Any oil in the water floats on the surface and runs to waste with a small quantity of water over the waste-weir. About 8 per cent. of the overflow is lost in this way. The remainder flows back to the basement reservoir through a return pipe taken off from the bottom of the tank, where the water is practically pure and free from any trace of oil. A valve fixed on this pipe regulates the proportion of water utilized to that run to waste. The object of the upward bend in the return pipe near the tank is to preclude the possibility of running the full contents of the tank with oil floating on the surface into the reservoir. Water drawn from the bottom of the separating-tank is perfectly clear, tasteless and odourless, and a qualitative analysis made by the chemical examiner to the Punjab Government showed it was chemically pure and fit for drinking purposes. The water from the separator is led off direct in a 6-inch pipe to the lower ends of the suction-pipes, into which it is discharged without mixing with the water in the reservoir.

The engines were tested 1 month after they commenced work and gave the following results:—

—	Engine A B.	Engine C D.
I.HP., calculated from diagrams taken from each cylinder	82·2	84·5
Pump HP., calculated from full displacement . . .	73·5	70·0
Effective HP., from actual work done	71·5	68·0
Slip . . . . per cent.	6·1	5·8
Mechanical efficiency . . . . ,,	84·0	78·0
Consumption of steam per pump HP. per hour . lbs.	22·95	23·2
Delivery of pumps at the head of rising main in 15 minutes at forty strokes per minute . . . gallons	2,600	2,580

Rising-Mains.—The rising-mains are in duplicate, of mild steel, 5 inches in internal diameter, ¼ inch thick, each capable of passing half the maximum daily supply in 12 hours or the whole in 24 hours at a velocity of 3 feet per second. By means of the cross connection before described, either or both mains can be used

with either engine or both mains with both engines. This arrangement admits of pumping the full supply through one line of pipes in 24 hours in the event of the other line being temporarily thrown out of work.

The joints of the tubes are made by inserting a flat rubber ring into a groove in one of the flanged ends of a pipe. A corresponding projection in the adjoining end of the next pipe fits into this groove, and is drawn tight against the rubber ring by cast-steel flanges and bolts. These joints proved most satisfactory, not a single case of leakage having occurred at a joint under the test pressures to which they were subjected.

The pipes are laid 3 feet apart, in a trench about 2 feet 6 inches deep. Dry-stone stop walls have been built across the trench at intervals of about 200 feet where the slope is steep. The pipes were laid in lengths of about 500 feet at a time, and were tested by a portable hand test-pump to a water-pressure of 800 lbs. to the square inch before being covered. The pipe lines are elastic and need no provision for expansion and contraction. The length of the mains measured along the hillside is 2,700 feet, and the difference of level between the pumps and the small iron tank into which they discharge at the summit is 1,255 feet. This tank consists of a cylinder of $\frac{1}{4}$-inch boiler plate, 10 feet in diameter and 10 feet high, and is provided with the usual inlet, outlet, overflow and scour fittings. The pipes cost in England £875, or Rs.14,000, and laid complete in India Rs.21,500.

Gravitation Main.—This main is of cast-iron, spigot and socket, with lead joints. It takes off from the tank at the summit of the rising-mains and runs alongside the old waterworks main on the Hindustan-Thibet road to the first storage-reservoir, known locally as the Sanjauli reservoir. A connection is made with the old main at the toll bar by means of which the latter, which runs only partly full during the hot months, is utilized for carrying a part of the supplementary supply from the pumps. This connection also enables the engine-driver to fill the rising mains before starting the engine, by backing the gravitation supply into them from the old main. The pipes are 8 inches in diameter up to the Sanjauli reservoir. A by-pass at this reservoir carries the new line forward towards the "Church reservoir" in the centre of the station. This continuation is 7 inches in diameter and runs into the old main at a distance of 4,000 feet from the Sanjauli reservoir, the hydraulic gradient at which the old main is laid beyond this point being sufficiently steep to discharge the combined supply into the Church reservoir, Fig. 2.

Cost.—The cost of the works is given below under the different heads. When the work was carried out the exchange rate of a rupee was 1*s.* 3½*d.* The amounts do not include general charges on account of supervising establishment, tools and plant, compensation for land, &c.

	Rupees.
Separating-weir	3,200
Filters	18,750
Pumping-station and feed-reservoir	39,000
Pumping-engines and boilers	88,500
Workshop	8,000
Staff quarters	6,500
Rising mains	21,500
Cast-iron piping and valves	60,600

The cost of establishment for a season's work, that is, for 3 months, amounts to about 1,000 rupees, and this includes the pay of a European engine-driver for 3 months at Rs.200 per month. The cost of small stores, including such materials as lubricants, red lead, white lead, cotton waste, &c., for the same period is 125 rupees. The fuel used is principally dry oak which costs 40 rupees per hundred maunds (one maund = 82 lbs.) cut and stacked at the pumping station. The rate of consumption is 65 maunds of firewood per 100,000 gallons pumped.

The Paper is accompanied by two tracings, from which Plate 5 has been prepared.

(*Paper No. 3018.*)

"Amballa Waterworks."

By CHARLES ERNEST VERE GOUMENT, Assoc. M. Inst. C.E.

AMBALLA, an important town in South Punjab, lies at the junction of the East Indian and North-Western Railway systems, and is on the direct route to Simla, the summer capital of India.[1] The city contains a population of about 25,000, and has long felt the need of a good water-supply. The wells in the town are practically dry in May and June, and the distress caused by the scarcity of water in these hot months has been very severe. The Government recognized this want so long ago as 1854, when levels were taken with a view to introducing water from the River Ghaggar, about 20 miles from the town; and various schemes have since been considered and set aside. The chief obstacle was paucity of funds, but this was at length overcome in 1890 by the action of the late Deputy Commissioner, Mr. C. E. Gladstone, who raised nearly half the full amount required by private contributions, and obtained a grant of the other half from the local Government.

The scheme recently completed for supplying the town with water from wells sunk near the Tangri river was initiated in 1887 by Mr. J. W. Wright, M. Inst. C.E., superintending engineer, and Mr. B. G. Wallis, executive engineer. The project prepared by these officers was modified in 1891 by Mr. J. M. Campion, M. Inst. C.E., then executive engineer of the Amballa Division, whose estimate received the sanction of Government. Finally, the scheme was revised in 1894 by the Author, who has carried out the work, the total cost of which has been about Rs.3,46,000.

The works were calculated to supply 7 gallons per head for a prospective population of 30,000, the population according to the last census being 25,200. In addition to this, about 15,000 gallons a day were to be supplied to the police and civil lines and 22,500

[1] About 4 miles from the city is a large military cantonment of the same name. The cantonment water-supply has no connection with the works described in this Paper.

gallons to the gaol, making the total maximum daily supply 247,500 gallons. The supply is derived from twenty wells situated about 8 miles from the city, on the right bank of the Tangri river, Fig. 1, Plate 6. The water table at the site of the wells is 6 feet below the ground-level and falls towards Amballa, where it is more than 30 feet below ground-level. The ground also falls towards the town, the difference of level being about 45 feet. The water is conveyed to the town through an 8-inch iron main by a dual system which combines gravitation and pumping. The former, taking advantage of the natural slope of the ground and water table, delivers about 4,000 gallons per hour into the service-reservoir in the city when the pumps are not working. The pumps supplement the gravitation supply and force the remainder through the same main at a velocity of 3 feet per second, which scours out the main and keeps it free from sedimentary deposits. The water is delivered in the town into an elevated circular steel reservoir, which rests on a circular brick tower 26 feet high, and holds 1 day's supply. It is distributed from this tank through a network of cast-iron piping, varying between 12 inches and 3 inches in diameter, and seventy-five standposts placed at convenient points in the streets.

Wells and their Connections.—The site of the wells is a tract of sandy waste land between the Tangri river and one of its main branches; about $\frac{3}{4}$ mile from the former and $\frac{1}{4}$ mile from the latter. Both these channels run full and discharge a large quantity of water during the monsoon months—July to September—but they are dry for the rest of the year. There are no villages, tanks or other sources of pollution within a considerable distance of the wells, but, as an additional safeguard, an area of 2,000 feet by 1,000 feet has been taken up round the wells and is strictly preserved. The wells are constructed of bricks in lime mortar and are covered with a concrete dome as shown in Fig. 4, Plate 6. Their internal diameter is 7 feet, and they are pitched 60 feet apart, centre to centre, in a line normal to the direction of slope of the water table. The depth of the wells is about 40 feet. They all terminate in sand of varying degrees of coarseness. Six wells in the middle of the line are entirely in sand. The rest have passed through bands of clay of varying thickness. The water-level is about 6 feet below the surface and its extreme fluctuation, as observed at different times of the year for several years, has not exceeded 15 inches above or below this level. It is possible, however, it may fall even lower for a few months before the monsoons in an exceptionally dry

year, but the heavy rainfall of the monsoon months, July to September, and floods in the Tangri will always, it is believed, restore it to its normal level. The estimated yield of the wells had been based on extensive experiments on trial wells sunk on the site. These experiments had been made on single wells and showed that a well 7 feet in diameter would yield 15 gallons per minute under a head of 7 feet. It had therefore been assumed that twenty such wells, pitched at such a distance apart as to avoid intersection of the deeply-depressed portions of their surrounding cones of exhaustion (as observed at the trials) would yield, approximately, 300 gallons per minute. The actual yield of the wells placed 60 feet apart is, however, found to be only about 195 gallons per minute. The cones of exhaustion round the wells are now somewhat larger than those observed during the trials, but the difference is not considerable and would not altogether account for the actual yield being so much lower than that estimated. The main reason for the difference would seem to lie in the very variable character of the soil. The yield of each well has been tested independently by noting its rate of recoupment after it had been pumped down 7 feet below normal, and it is found that the yield of the different wells is very variable. The recoupment of some of the wells, which are in very coarse sand, is found to be better than that observed in the trial wells from which the estimate was formed; while others, in finer sand, do not give nearly such good results. At present the supply from twenty wells is sufficient, but the demand must increase considerably in the near future. When a larger supply is required more wells will be added and connected with the present system. The cost of one well, complete with all fittings, is about Rs.1,000, or £60. The bottoms of the wells have been loaded with 2½-inch stone ballast, 6 feet deep, to prevent sand "creeping" into them, but it has been found that this loading, though it effectually prevents "blows," does not completely check the gradual ingress of sand under the head to which the wells are pumped, viz., 7 feet. The increase of sand at the bottoms of the wells is, however, very slow, and it is believed that it will stop when the accumulation has reached a certain limit.

The wells are connected by a line of 9-inch cast-iron pipes laid parallel to the line of wells with 4-inch pipe connections to each. These pipes are laid 3½ feet below normal spring-level, and act as suction-pipes for the pumps when these are working, and collecting-pipes for the gravitation main when the pumps are not

at work. The valves and connections which control the system are shown in Figs. 3 and 4. As these pipes are laid under water in a treacherous sandy soil they are provided with flexible joints. The main 9-inch pipes have Maclaren rubber joints, Fig. 5, and the joints of the 4-inch branches are ball and socket, Fig. 6. The depth at which the connecting-pipes are laid, viz., 3½ feet below ordinary spring-level, has been fixed by the following considerations: 18 inches has been allowed as the maximum fall of water-level due to continued dry weather and other causes (the maximum observed being only 15 inches); the other 2 feet give the head, under which, as ascertained by previous experiments, the wells are capable of yielding the full supply which the gravitation main can carry away at the gradient at which it is laid.

Pumping Machinery.—The pumping-engines and boilers have been supplied by Messrs. James Simpson and Company. There are two engines and two boilers. Each engine is capable of forcing 375 gallons per minute with a velocity of 3 feet per second through an 8-inch main 8 miles long, which has a fall in this length of 17 feet from the axis of the pumps to the high-water level of the service-reservoir in the city. The pipes being at present new and smooth, the hydraulic pressure registered by the gauge at the pumps when the engines are doing this duty is only 160 feet; but the engines are designed to deliver the water with a velocity of 3 feet per second under a head of 242 feet, to which it is calculated the pressure will rise when the main becomes encrusted and rough after some years' use.

Each engine and boiler is capable of performing the full duty. The boilers are of the ordinary Babcock-Wilcox pattern. The engines are of 30 HP. and of the compound horizontal condensing fly-wheel type. An air-ejector is fixed above the pump-barrels to draw water into the pumps and charge them fully before the engines are started. This is accomplished in the ordinary way by blowing steam through the ejector and creating a vacuum. The ejector does away with the necessity of having foot-valves on the suction-pipes in the wells, which would have offered obstruction to the gravitation flow. As the delivery-main falls away from the pumps, a loaded valve is fixed on it to give the engines a load when they start.

The suction-pipes, 9 inches in diameter with flange joints, are just laid above ordinary water-level, and join the 9-inch pipe-line connecting the wells in the middle of its length by a vertical bend and tee-pipe. A stop-valve is fixed on each side of this connection,

which enables half the wells to be cut off at any time for examination or repairs while the other half are still available for supplying the town.

The delivery-main is 8 inches in diameter, and it is 3,400 feet in length to its junction with the gravitation main. It might have joined the gravitation main immediately beyond the pumping-station; but as that main is below spring-level for a distance of 3,400 feet from the wells, and is not easily accessible for repairs, it was deemed advisable to lay a second line of pipes for the pump-delivery at a depth of 3 feet below ground up to the point where the gravitation main emerges above spring-level.

Gravitation Main.—This main is 8 inches in diameter, and it is laid below a hydraulic gradient line drawn from the high-water level of the service-reservoir in the town to the level of the pipes connecting the wells, Fig. 2. For a distance of 3,400 feet from the wells, the pipes are laid below spring-level, and have flexible rubber joints. From this point onwards the pipes are turned and bored with the usual percentage of lead joints to allow for expansion and contraction. The length below water-level is provided with hatch-pipes and manholes every 500 feet, to facilitate inspection and location of accidents. A stop-valve is fixed at the head of this length where it takes off from the connection-pipes of the wells, and another at its lower end where it is joined by the delivery-pipes from the pumps, Fig. 3. By closing these two valves, this length of pipes is cut off entirely from the pumping system. An open vertical pipe is fixed near the stop-valve at the upper end, which acts as an air-escape, and also provides a means of scouring this length by pumping back through it from the point where it is joined by the delivery main.

Beyond the junction of the two mains the pipes are laid in the ordinary manner at a mean depth of 3 feet below ground. There are 4-inch scour-valves at each depression, and 1½-inch air-valves at each summit, or every 5,000 feet where summits do not occur for long distances.

Service-Reservoir.—This reservoir, Figs. 7 and 8, was designed by the Author on the principle of the Norton Tower on the Vyrnwy Aqueduct,[1] constructed by Mr. G. F. Deacon, M. Inst. C.E. It compares favourably in cost with other designs, and the economy of the design would obviously have been greater if the tower had been higher. Its other advantages are: (1) the accessibility of all its parts for periodical painting and repairs; (2) its perfect

[1] Minutes of Proceedings Inst. C.E., vol. cxxvi. p. 61.

freedom for expansion and contraction from variations of temperature.

The spherical bottom and the hoop-girder from which it is suspended are built of mild-steel plates of special quality manufactured in Scotland, and the upper cylindrical portion is of wrought iron. The tank was constructed in India by Messrs. Burn and Company of Calcutta, who also erected it in position at Amballa. The inside of the tank is coated with asphalt varnish, composed of 1 part of asphalt and 2 parts of coal-tar, laid on in two thin coats. The cost of the tower was Rs.45,000, equivalent in English money, at the present rate of exchange, to £2,500. The capacity of the tank is 220,000 gallons.

There are two minor details of the design which the Author would point out as being capable of improvement. First, the upper angle-bar of the hoop-girder, A, Fig. 8, might with advantage be placed on the outer side; the inner rivet-heads could then be formed more conveniently and be more easily made watertight. The joint B is too near the masonry for convenient erection and riveting, and should have been at least 12 inches lower.

Distribution System.—A 12-inch pipe conveys the water from the service-reservoir to the city, where it is distributed by pipes of smaller diameters up to 3 inches through seventy-five standposts placed at convenient points in the streets. A by-pass at the reservoir makes a direct connection between the supply main and the distribution system, and allows of the reservoir being cut off at any time for repairs without interfering with the supply. The diameters of the distribution pipes are calculated to give a discharge of 10 gallons per minute through each standpost under the head available at the service reservoir when the water is at the level of the springing of the spherical bottom. Scour-valves are placed at the lowest points, and these are opened about once a fortnight to clean out the pipes. There are no dead ends, the system being connected everywhere to avoid stagnation of water in the pipes, and give a duplicate supply at every point. There is a stop-valve on every branch from the trunk lines. The standposts are plain but substantial, and cost £2 10*s.* each in England with street stop-cock and fittings. They are fitted with strong brass push-cocks.

Cost.—The cost of the main heads of work, exclusive of such general charges as compensation for land, cost of tools and plant, and supervising establishment, &c., is given in the following Table. The equivalents of these sums in English money may be calculated approximately by taking Rs.18 to a £.

	Rs.
Twenty wells	20,000
Pumping machinery, with chimney and building	60,000
Cast-iron pipes and valves at the headworks and from the headworks to the city	1,40,000
Service reservoir (capacity 220,000 gallons)	45,000
Distribution system (area served $\frac{3}{8}$ square mile)	60,000

Including all cast-iron pipes, valves, standposts, valve wells, manholes, &c.

The monthly cost of establishment entertained for the maintenance of the works is:—

	Rs.
One European engine-driver and general superintendent	115
„ native fitter	40
Two firemen	20
„ turnkeys	14
One engine cleaner and oil man	10
Petty establishment (watchmen, gardeners, &c.)	30
Total	229

The monthly expenditure for small stores, such as lubricants, cotton-waste, red-lead, white-lead, packing, &c., is about Rs.37. The fuel used for the engines is dry firewood costing Rs.25 per 100 maunds (one maund = 82 lbs.), cut and stacked at the pumping-station. The consumption at present is 21 maunds per 100,000 gallons pumped, but this will increase when the pipes become rough.

The works were commenced February 1894, and were formally opened by Sir Dennis Fitzpatrick, K.C.S.I., Lieut.-Governor of the Punjab, on the 11th November, 1895.

The Paper is accompanied by a tracing, from which Plate 6 has been prepared.

(*Paper No. 3050.*)

"The Finer Grinding of Portland Cement, and the Comparative Value of the Coarser Particles."

By David Butler Butler, Assoc. M. Inst. C.E.

The experiments described in this Paper were undertaken by the Author to investigate the generally-accepted theory as to the inertness of the coarser particles of Portland cement, the results of which suggested the subsequent series of researches as to the effect of extreme fine grinding. As a preliminary experiment, the coarser particles of cement A, Table I, were separated into three degrees of coarseness, viz., those which would not pass through a sieve having 50 meshes per lineal inch, those which passed a 50-mesh sieve and were retained on a 70-mesh, and those which passed a 70-mesh sieve and were retained on a 120-mesh, and briquettes formed from the grit thus obtained. To ensure that the cohesive strength developed was actually due to the cementitious value of the coarse particles themselves, and not to fine cement dust or flour adhering to them, each lot was thoroughly washed by shaking it briskly with water in a stoppered bottle, decanting the turbid fluid, adding fresh water, and repeating the operation until the water was no longer turbid; about ten changes of water sufficed for this purpose. The washed substance was then immediately filled into an ordinary briquette mould of 1 square inch section, lightly shaken, without ramming, to eliminate any air-bubbles, and placed under water. On examination a day or two afterwards, the mass was found to have hardened considerably, and in a few days, according to the size of the grit, it was sufficiently hard to bear removal from the moulds. The briquettes thus formed were tested for tensile strain at the end of 6 months and 12 months respectively, with the results given in Table I. As the 6 months' test indicated clearly that the coarse particles thus treated had a certain value, a set of experiments was instituted with four other cements, B, C, D and E. The results corroborated those obtained in the first instance, as will be seen on reference to the same Table.

The coarse residue has hitherto been considered inert, and by

TABLE I.

Cement No.	Size of Coarse Particles.	How Treated.	Tensile Strength in Lbs. per Square Inch.		
			28 Days.	6 Months.	12 Months.
A	Retained on 50 sieve.	Placed immediately in water . . .	..	150	160
„	Passed 50 and retained on 70 . .	„ „ „	..	200	200
„	Passed 70 and retained on 120 . .	„ „ „	..	250	330
B	Retained on 50 sieve	Placed immediately in water . . .	..	95	120
„	Passed 50 and retained on 70 . .	„ „ „	..	110	160
„	Passed 70 and retained on 120 . .	„ „ „	..	175	200
C	Retained on 50 sieve	Placed immediately in water . . .	..	90	120
„	Passed 50 and retained on 70 . .	„ „ „	..	110	170
„	Passed 70 and retained on 120 . .	„ „ „	..	190	280
D	Retained on 50 sieve	Placed immediately in water . . .	..	90	140
„	Passed 50 and retained on 70 . .	„ „ „	..	115	197
„	Passed 70 and retained on 120 . .	„ „ „	..	192	200
E	Passed 50 and retained on 70 . .	Placed immediately in water . . .	..	..	180
„	Passed 70 and retained on 120 . .	„ „ „	97	190	292
„	Passed 120 and retained on 180 . .	„ „ „	..	330	420

some authorities has been even regarded as an adulterant, but the above results conclusively demonstrate that such is by no means the case. The Author therefore proceeded to ascertain more exactly the relative value of the particles of different sizes, and also whether their total removal from the cement affected the strength of the material. If, after a considerable lapse of time, the coarser particles had a certain value, it seemed possible that the extreme fine grinding of cement might not be such an unmixed advantage as was generally supposed, but that it simply enabled the cement to more quickly attain its greatest strength, by reason of the water being able to more readily combine with

fine than with the coarse particles. In that case the ordinary 7-day or 28-day tests with very fine cements were more or less delusive, for though a finely-ground cement would show to greater advantage within such limited periods, the coarser cement would ultimately be equally strong; in other words, that the "growing" power of cement, or its property of increasing in strength with age, was largely due to the gradual incorporation of the coarser particles. The following experiments, though supporting this theory to a certain extent, conclusively demonstrate the advantages of finely-ground cement.

In order to procure a fair representation of English cements, samples were obtained from the principal manufacturers in the four chief centres of the industry, viz., cement F from the Lias districts of Warwickshire, cement G from the Northfleet shore of the Thames, cement H from the Grays shore of the Thames, and cement I from the Medway district. Comparative tests were made of each sample under the following conditions: (1) As received from the manufacturer; (2) reground (in the Author's mill) so as to practically all pass a 180-mesh sieve; (3) all particles removed that would not pass a 180-mesh sieve, and an equal quantity of grains of sand of exactly the same size substituted. The value of each cement thus treated was ascertained by determining its tensile strength in the ordinary way at 7 days, 28 days, 3 months, 6 months and 12 months, both neat and with 3 parts of standard sand, and the results of this series of tests are given in Table II.

Referring first to cement F, it will be seen that the effect of grinding it extremely fine is that when gauged neat it is slightly stronger than the original cement at 7 days, but shows very little increase at the 28 days, and then gradually falls off, being 22 per cent. weaker at the end of 12 months than the original cement. The 3 to 1 sand briquettes, on the other hand, are 89 per cent. stronger at 7 days than similar briquettes made with the original cement, and continue to increase, till, at the end of 3 months, they are actually stronger than the neat briquettes, while at the end of 12 months they are not only 32 per cent. stronger than the sand briquettes of the original cement, but are within 3 per cent. of the strength of the original cement gauged neat.

The effect of substituting sand for the coarser particles is to weaken both the adhesive and cohesive power of the cement, especially at the earlier dates, although at 12 months the neat briquettes thus prepared appear to have nearly caught up the original cement. The results obtained with cements G, H and I, corroborate cement F fairly well, and although in some instances

TABLE II.

Cement.	How Treated.	Fineness-residue per cent. on Sieves of Meshes per Lineal Inch:			Setting Properties.		Percentage of Water used for Gauging Briquettes.		Tensile Strength in Lbs. per Square Inch.									
									Neat Cement.					3 parts Sand to 1 part Cement.				
		180	76	50	Initial Set.	Set Hard	Neat.	Sand.	7 Days.	28 Days.	3 Mons.	6 Mons.	12 Mons.	7 Days.	28 Days.	3 Mons.	6 Mons.	12 Mons.
					Mins.	Mins												
F	As received from manufacturer . . .	33·0	16·0	4·0	15	90	21·66	7·81	483	572	623	662	653	183	276	383	440	482
,,	Reground extremely fine	2·5	Nil	Nil	4	60	25·00	9·38	498	541	538	531	506	347	452	564	599	637
,,	{All particles not passing 180 sieve removed and sand of similar size substituted .}	..	..	..	..	..	18·33	7·81	418	456	567	596	650	153	210	272	337	386
G	As received from manufacturer . . .	35·0	20·0	8·0	10	90	20·00	7·81	495	618	622	694	759	187	245	334	377	392
,,	Reground extremely fine	1·0	Nil	Nil	1	4	25·00	8·13	540	474	560	466	477	282	363	494	595	617
,,	{All particles not passing 180 sieve removed and sand of similar size substituted .}	..	..	..	..	..	18·33	7·81	403	448	602	678	714	158	209	303	348	378
H	As received from manufacturer . . .	28·0	11·0	4·0	8	60	19·16	7·81	445	493	584	663	706	167	230	312	373	399
,,	Reground extremely fine	0·8	Nil	Nil	2	5	26·66	8·18	433	501	514	482	535	287	364	508	585	599
,,	{All particles not passing 180 sieve removed and sand of similar size substituted .}	..	..	..	..	..	18·33	7·81	367	453	604	669	692	145	212	271	348	405
I	As received from manufacturer . . .	39·0	15·0	2·5	20	120	20·00	8·59	592	639	786	791	751	240	297	389	425	410
,,	Reground extremely fine	0·8	Nil	Nil	2	10	30·17	11·26	417	394	459	476	498	387	465	560	585	618
,,	{All particles not passing 180 sieve removed and sand of similar size substituted .}	..	..	..	..	..	18·33	7·42	470	565	653	698	754	200	246	312	382	380

TABLE III.

Cement.	Size of Coarse Particles.	How treated.	Tensile Strength in Lbs. per Square Inch.			
			28 Days.	3 Months.	6 Months.	12 Months.
F	Retained on 50 sieve . . .	Placed immediately in water	..	..	95	130
”	Passed 50 and retained on 76 .	” ”	..	..	120	170
”	Passed 76 and retained on 120 .	” ”	..	..	245	300
”	Passed 120 and retained on 180	” ”	..	..	310	360
”	Entire residue retained on 180 .	” ”	..	150	230	290
G	Retained on 50 sieve . . .	Placed immediately in water	..	..	47	70
”	Passed 50 and retained on 76 .	” ”	..	..	105	165
”	Passed 76 and retained on 120 .	” ”	..	..	175	300
”	Passed 120 and retained on 180	” ”	..	..	185	410
”	Entire residue retained on 180 .	” ”	48	133	158	262
H	Retained on 50 sieve . . .	Placed immediately in water	..	..	92	145
”	Passed 50 and retained on 76 .	” ”	..	..	132	235
”	Passed 76 and retained on 120 .	” ”	..	..	200	385
”	Passed 120 and retained on 180	” ”	..	..	280	360
”	Entire residue retained on 180 .	” ”	72	142	212	272
I	Retained on 50 sieve . . .	Placed immediately in water	..	..	47	85
”	Passed 50 and retained on 76 .	” ”	..	..	80	145
”	Passed 76 and retained on 120 .	” ”	..	..	122	225
”	Passed 120 and retained on 180	” ”	..	..	280	430
”	Entire residue retained on 180 .	” ”	53	110	170	260

the substitution of particles of sand for the coarse particles of cement does not seem to affect the result to the same extent, in every case the extreme fine grinding decreases its cohesive power, but immensely increases its adhesive power or cementitious value. These results demonstrate clearly that in testing cement, to determine its constructive value, the neat test alone may be altogether delusive. It will be seen that in each case the fine

cement is far inferior to the coarse one when tested neat, yet its cementitious value, as indicated by its power of cementing together particles of sand, is immensely superior. Until recently the Author was strongly adverse to the adoption of the sand test, inasmuch as it first involved the testing of the sand, thus adding a further element of error; but when it is found that a very finely-ground cement, with more than 30 per cent. greater cementitious value, gives inferior results when tested neat, there is no doubt as to which is the truer test of the two. Moreover, in the course of recent researches as to the effect of admixtures of Kentish Ragstone, &c., upon Portland cement, the Author found that it was possible, in some cases, to add as much as 20 per cent. to 30 per cent. of finely-ground sand to a cement without materially affecting its strength when tested neat, although when tested as a mortar with 3 parts of standard sand the adulteration was immediately detected.[1]

The coarse residue separated from each of the foregoing samples was divided into different grades, and was washed and treated in an exactly similar manner to samples A, B, C, D and E, with the results given in Table III. Although the method adopted to avoid the possibility of fine dust adhering to the particles was severe, the results show that at all events in wet situations, where water is able to act upon them, the coarser particles of cement have a distinct value, and that this value is, roughly speaking, inversely proportional to the diameter of the particles. A microscopic examination of a section of a briquette composed wholly of such coarse particles shows that each particle is surrounded and cemented together by a white deposit of a crystalline nature; this deposit, in briquettes composed of residue on a 50-mesh sieve of cements C and D, was separated mechanically as far as possible, and proved on analysis to consist as follows:—

—	C.	D.
Carbonic acid	11·80	14·00
Water	24·90	20·60
Insoluble residue	trace	trace
Silica	8·12	6·42
Alumina and oxide of iron	9·22	8·47
Lime	43·47	48·57
Magnesia	0·99	0·59
Sulphuric acid	1·35	1·11
Alkalies and loss	0·15	0·24
	100·00	100·00

[1] Transactions of the Society of Engineers, 1896, p. 179.

A noteworthy feature of its composition is, that the percentage of alumina is considerably greater than that of the silica, thus reversing the composition of the cement proper, in which the amount of silica is generally about double that of the alumina, and indicating that the crystals consist largely of the more soluble aluminate of lime.

The foregoing results together suggest that the outer surface only of the coarser particle is acted upon or dissolved by the water, and as the finer the particle, the greater the area of such outer surface exposed to the action of the water within a given space, the greater is the cementitious value of that particle. At what fineness the particle becomes wholly active, and contains no internal inert matter, has yet to be determined; it seems, however, from these experiments, that those particles which pass through a 120 and are retained on a 180-mesh sieve, nearly approach that point, inasmuch as at 12 months they develop about four-sevenths of the strength of the original cement, notwithstanding the drastic treatment to which they were subjected in order to remove any trace of adhering dust.

It will be noticed in Table II that the finer grinding has a marked effect on the setting properties of the cement; sample I, for instance, commencing to set in 20 minutes in its original condition, while, when ground fine, its initial set is quickened to 2 minutes. This induced the Author to ascertain the effect of extreme fine grinding upon other samples, the results of which are given in Table IV. It will be seen in each instance that the finer grinding of the sample enormously quickens its setting properties. Although this fact is not generally recognised, its explanation is obvious, for it is evident that the finer the cement, the more readily the water can act upon it, and therefore the quicker the setting takes place. According to Le Chatelier the setting of cement is due to the formation of a supersaturated solution, which gradually deposits crystals until a solid mass is formed; if this theory is correct, it is clear that the finer the cement the more readily it dissolves, and therefore the sooner the supersaturated solution forms, and the quicker the crystals are deposited.

About 15 years ago it was the custom to determine the heat evolved by a cement during setting, as indicating its setting properties, and when the pat had returned to its original temperature, the sample was considered set. This test was shortly afterwards abandoned, and the present test of a weighted needle substituted, which is obviously the truer test for the purpose, for it is not easy to see the relation between the return to normal temperature and

TABLE IV.

Cement.	How Treated.	Fineness-residue per cent. on Sieves of Meshes per Lineal Inch:			Setting Properties.		Increase in Temperature during Setting.	Return to Normal Temperature.	Pat treated in Faija Apparatus for Soundness.
		180	76	50	Initial Set.	Set Hard			
					Minutes.	Minutes	°F. Mins.	Ms.	
J	As received from manufacturer	22·4	6·0	Nil	25	45	22 in 40	120	Sound.
„	Reground to pass 180 sieve	Trace	Nil	Nil	1	5	38 in 5	90	„
K	As received	26·6	10·0	2·7	30	90	17 in 100	240	Sound.
„	Reground as above	Trace	Nil	Nil	6	15	32 in 11	150	„
L	As received	24·4	7·6	1·5	30	120	9 in 60	180	Blown.
„	Reground as above	Trace	Nil	Nil	7	15	29 in 13	120	Sound.
M	As received	30·0	6·7	1·2	20	60	21 in 34	150	Sound.
„	Reground as above	Trace	Nil	Nil	2	10	26 in 8	75	„
N	As received	28·4	9·3	1·0	15	30	25 in 21	120	Sound.
„	Reground as above	0·6	Nil	Nil	1	10	32 in 4	120	„
O	As received	26·4	7·7	0·5	Undefinable	360	2 in 39	160	Sound.
„	Reground as above	0·4	Nil	Nil	8	25	27 in 12	95	„
P	As received	18·0	3·0	0·8	15	240	15 in 23	120	Badly blown.[1]
„	Reground as above	0·4	Nil	Nil	2	240	23 in 5	100	Very slightly blown.[1]
„	As received mixed with 2 per cent. gypsum	18·0	3·0	0·8	Undefinable	1,440	1 in 15	35	Blown.[1]
Q	As received	34·8	16·0	3·6	20	30	17 in 35	180	Badly blown.
„	Reground as above	1·6	Nil	Nil	2	5	26 in 5	180	Sound.
	As received mixed with 2 per cent. gypsum	34·8	16·0	3·6	Undefinable	1,440	1 in 15	30	Blown.

[1] A specially-prepared "over-limed" cement; see analysis, Table V.

the setting of the sample. Mr. G. F. Deacon has advocated[1] the determination of the rise of temperature during setting as a test for "free lime." The Author, however, doubts the utility of this test, and has expressed[2] the opinion that the rise of temperature during setting of a cement is due rather to the heat evolved by crystallization or setting than to the presence of "free lime," and that such a test therefore only ensures an extremely slow-setting cement, and in no way ensures a sound one. To ascertain the relation between the setting properties of cement and the heat evolved during setting, and also how far the theory was correct, that little or no increase in temperature pointed to the absence of "free lime," that is, a sound cement, the rise of temperature during setting of each sample in Table IV was also noted, and in each case it was found to bear a distinct relation to the time occupied in setting.

TABLE V.—ANALYSES OF THE PRINCIPAL CEMENTS USED IN THE FOREGOING EXPERIMENTS.

—	F.	G.	H.	I.	P.	Q.
Water and carbonic acid	1·70	1·55	1·40	1·55	1·25	1·45
Insoluble residue	0·98	1·08	0·77	0·68	1·49	1·17
Soluble silica	20·98	20·75	21·04	20·05	21·43	20·57
Alumina	8·41	7·48	8·17	8·55	5·77	6·46
Oxide of iron	4·02	3·81	4·21	3·94	3·51	5·83
Lime	60·55	62·01	61·23	62·19	64·20	62·09
Magnesia	1·29	1·14	1·27	1·23	1·08	1·34
Sulphuric acid	1·67	1·83	1·39	1·49	0·68	1·12
Alkalies and loss	0·40	0·35	0·52	0·32	0·59	0·47
	100·00	100·00	100·00	100·00	100·00	100·00

Each sample was also tested for soundness in the Faija apparatus[3] and the results recorded; it will be seen that cement L, in its original condition, was unsound, although it only showed an increase of 9° in 60 minutes; when extremely finely ground the heat evolved during setting was 29° in 13 minutes, and the fine grinding had rendered it perfectly sound. The latter result was surprising, and efforts were thereupon made to procure one or two unsound cements, and ascertain the effect of grinding them extremely fine. Cement P was specially prepared for the Author as an over-limed, unsound cement; when treated in the Faija apparatus it "blew" badly, and disintegrated almost entirely, but after being ground extremely fine, this "blowing" characteristic had

[1] Minutes of Proceedings Inst. C.E., vol. cxxvi. p. 46.
[2] *Ibid*, vol. cxxvi. p. 103. [3] *Ibid*, vol. lxxv. p. 213–30.

practically disappeared. Cement Q, on the other hand, was a badly manufactured cement, being made from a very hard chalk, insufficiently reduced during the amalgamation of the raw materials. This sample also "blew" very badly when treated in the Faija apparatus, but after being ground extremely fine, these indications disappeared entirely.

To ascertain more conclusively whether the action of setting or the presence of "free lime" was responsible for the rise in temperature noted, cements P and Q in their coarse condition were mixed with 2 per cent. of gypsum, which, as is well known, retards the setting of cement; the result was that they were thus rendered extremely slow setting, and while still unsound, and giving decided indications of "blowing" in the Faija apparatus, they showed an increase during setting of only 1°. As, therefore, the rise of temperature during setting depends upon the setting properties of the cement, and in no way determines the presence of "free lime" or other disruptive agencies, the Author is strongly of opinion that to enforce such a test, while it certainly ensures the delivery of a very slow-setting cement, which in view of the method of working adopted by Mr. Deacon was absolutely imperative, in no way guards against an unsound cement, and imposes needless restrictions upon the manufacturer. Unsound over-limed cements are generally slow setting, and therefore evolve little or no heat during setting, while, on the other hand, a case lately came under the Author's notice of a cement which withstood the severe hot-water test of Deval, and yet showed an increase of as much as 25°.

That the finer grinding of cement should, to a considerable extent, correct a tendency to "blow," is a most important feature, the reason of which may be readily explained. "Blowing" or unsoundness may generally be traced to one of two distinct faults in manufacture, viz., over-liming or excess of lime, under-burning or insufficient calcination, both giving rise to the presence of free or loosely combined lime. In the first case the cement contains more lime than the silica and alumina can properly combine with, and in the second, insufficient heat has been applied to enable the lime to chemically combine with the other constituents. Of these two forms of unsoundness, by far the most insidious and dangerous is that due to over-liming, as the uncombined lime is confined within the hard-burned coarser particles, and it may be weeks or even months before the water can penetrate sufficiently to cause it to expand and betray its presence. The unsoundness due to under-burning, on the other hand, is comparatively harmless, and is gener-

ally detected within a day or two; in contradistinction to the unsoundness due to over-liming, which often causes the cement to crumble and disintegrate entirely, the under-burnt material behaves in much the same way as a fresh hydraulic lime, *i.e.*, a few slight cracks, and nothing further ensues. The beneficial effect of fine grinding, therefore, is that the uncombined lime, which would otherwise be confined within the coarser particles and subsequently cause mischief, is hydrated by the water during the operation of gauging, and thus rendered innocuous, or, if the cement has been previously spread out to mature, the moisture in the atmosphere acts upon it in a similar manner.

The effect of fine grinding on the setting properties of cement is a more serious matter, as in some instances it may render it too quick-setting for proper use. The tendency during the past few years has been to demand a finer cement, and at the same time a slow-setting one. The experiments in Tables II and IV show these two characteristics to be absolutely antagonistic, and unless it is rendered slow-setting artificially, a finely-ground cement means a quick-setting one, according to the degree of fineness attained. There are two methods of rendering a cement slow-setting: first, by thorough aeration, by which means the aluminate of lime becomes partially hydrated and its activity modified; secondly, by the addition of small percentages of gypsum ground up with the clinker in the course of manufacture. The latter method is largely practised in Germany, and within 2 per cent. the addition of that material is sanctioned by the German Cement Manufacturers Association. The ultimate effect of an addition of gypsum has not, in the Author's opinion, been sufficiently investigated to authorize its being accepted without reserve; his experience is that the addition of very small quantities, even as little as ½ per cent., will materially modify the quick-setting properties of a cement, but it seems somewhat easy to overstep the mark, inasmuch as 5 per cent. causes decided disintegration. According to certain continental authorities, the addition of gypsum should not be sanctioned where the cement is to be used in sea-water, as the salts contained therein have a very prejudicial effect upon cements containing such admixtures.

The Author therefore concludes:—

(1) The coarser particles of cement are not inert, but have a certain value, approximately in inverse ratio to their diameter.

(2) The extreme fine grinding of cement decreases its cohesive power, but immensely increases its adhesive power, and consequently its value *quâ* cement. Therefore to ascertain the true

constructive value of a sample, it should always be tested with a certain proportion of sand in addition to being tested neat.

(3) The finer grinding of cement immensely quickens its setting properties, and therefore allowance should be made in this respect, unless admixtures of gypsum or other artificial means of rendering it slow-setting are to be permitted.

(4) The finer grinding of cement largely corrects a tendency to unsoundness. A cement that would be totally unfit for use on this account when coarsely ground, would be perfectly reliable when extremely fine, owing to the water being able to attack the uncombined lime during the operation of gauging, instead of weeks or, maybe, months afterwards, when confined within the coarse particles.

(5) Increase in temperature during setting is governed by the setting properties of the sample. The setting of cement, being a process of crystallization, evolves heat; and the quicker the setting, the more intense the action, and therefore the greater the rise of temperature. That the cement shall show little or no rise of temperature during setting, ensures an extremely slow-setting cement, but does not guard against an unsound one.

With the exception of cements F, G, H, I, and P, which were chosen for the special reasons stated, the samples used in the experiments were not selected for that purpose, but were ordinary English cements passing through the Author's hands for testing in the usual course. Cements B and G were made by the same manufacturers, also samples H and L; but the remainder emanated from different factories.

The Paper is accompanied by six micro-sections of briquettes, and by photographs of pats treated in the Faija apparatus, which may be consulted at the Institution.

(*Paper No. 3064.*)

"Cement Concrete."

By Francis John Preston, Assoc. M. Inst. C.E.

Much vagueness still exists as to the method of correctly apportioning the component parts of cement concrete. In a note[1] read before the Conference of the Institution in May, 1897, Mr. John Kyle, M. Inst. C.E., gives the following: "Proportion of Materials: . . . . if of hand-broken metal, say 4 parts to pass a 3½-inch ring, 2 to pass 1¼-inch, and 2 gritty sand and 1 of cement." If it is admitted that in making good concrete it is essential that all the interstices of the aggregate should be filled with mortar, and that a small surplus of mortar should be allowed for surrounding the stones, such concrete cannot possibly be made with the proportions quoted, nor indeed with 6 parts of any ordinary-sized broken stone. Further, such concrete cannot be made if proportions of 1 of cement, 2 of sand and 7 or more of shingle are used, as they often are. Even 6 parts of shingle leave only a small margin of mortar in excess of interstices. One part of cement and 2 parts sand make $\frac{(1 + 2)\,3}{4}$ parts $= 2 \cdot 25$ parts of mortar; or, if the quantity of mortar is given, then the quantity of cement and sand will be ⅓ part greater. Slight variations, depending on the kind of sand employed, may occur.

The percentage of interstices of several samples of broken stone of the kind mentioned averaged 48 per cent. The percentage of interstices of several samples of shingle tested varied between 33 per cent. and 38 per cent. It is given[2] by Mr. J. W. Sandeman, M. Inst. C.E., as 50·9 per cent. for broken stone and 33·6 per cent. for gravel. With a concrete composed of 1 part of cement, 2 parts of sand, and 6 parts of broken stone, with 48 per cent. of interstices, the following results are obtained:—

		Parts.
Mortar $= \frac{(1 \text{ part cement} + 2 \text{ parts sand})\,3}{4}$	. . . =	2·25
Interstices = 6 parts × 0·48	. . . . =	2·88

[1] Engineering Conference, 1897. Notes, Sect. II, 25 May, No. 1*a*, "Concrete in Relation to Marine Works," p. 2. In the Library Inst. C.E.

[2] Minutes of Proceedings Inst. C.E., vol. liv. p. 260.

That is to say, the interstices are largely in excess of the mortar provided, and 10½ per cent. of the concrete will be made up of hollow spaces.

In the case of concrete composed of 1 part of cement, 2 parts of sand and 7 parts of shingle, taking the lowest percentage of interstices, viz., 33 per cent. :—

		Parts.
Mortar (as before)	=	2·25
Interstices = 7 parts × 0·33	=	2·31

With 1 part of cement, 2 parts of sand, and 6 parts of shingle :—

		Parts.
Mortar (as before)	=	2·25
Interstices = 6 × 0·33	=	1·98
Mortar in excess of interstices	=	0·27

So that the mortar is 5 per cent. of the aggregate in excess of the interstices, which is barely sufficient.

Of broken-stone concrete, therefore, made according to the proportions quoted, 10½ per cent. would consist of hollow spaces. It is possible that such concrete may be good enough for the purposes for which it was intended, but it cannot be generally recommended.

In order to correctly determine the component parts of concrete, it is necessary (1) To fix the proportion of cement to sand to be used; 1 to 2 will be found a useful proportion for most works. (2) To ascertain the quantity of mortar the selected proportion will make. (3) To know approximately the percentage of interstices of the aggregate. (4) To fix a certain percentage of mortar in excess of the interstices for surrounding the stones and to cover variations in the percentage of interstices of the same aggregate. Mortar equal to 10 per cent. of the aggregate is usually ample.

The percentage of interstices can be ascertained sufficiently approximately by filling a tank, the cubic contents of which are known, with samples of the aggregate. If the tank is then filled with water to the top, *i.e.*, if all the interstices are filled and the quantity of water required is noted, the percentage of interstices can be calculated. If, as a check, the water is drawn off and measured again, the percentage of interstices must lie between the water filled in and that drawn off; or, if the materials used absorb much water they should be soaked before being placed in the tank.

The following examples are given to show how the ratios of cement, sand and aggregate per 100 parts of finished concrete can be correctly ascertained.

(1) In this case the proportions selected are, 1 part of cement, 2 parts of sand, and broken stone having 48 per cent. of interstices; the amount of mortar required in excess of interstices to be equal to 10 per cent. of aggregate.

Then if	$x =$	aggregate without excess of mortar,		
	$x + \frac{1}{10}x =$	100 parts of finished concrete,		
and	$x =$	90·90 parts = aggregate.		
Mortar in excess of interstices .	=	9·09	„	(10 per cent. of aggregate).
		99·99	„	

			Parts.
Interstices (to be filled with mortar)	= 90·9 × 0·48 . .	=	48·63
Mortar in excess of interstices	= 90·9 × 0·10 . .	=	9·09
	Total mortar required . .	=	52·72
To find cement and sand add $\frac{1}{3}$		=	17·57
and divide by		3)	70·29
Cement, 1 part		=	23·43
Sand, 2 parts		=	46·86
Aggregate		=	90·90
			161·19

It will be seen that with this class of stone barely 4 parts can be used to 1 of cement.

(2) One part of cement, $2\frac{1}{2}$ parts of sand, shingle having 30 per cent. interstices; mortar in excess of interstices to be equal to 15 per cent. of aggregate.

If	$x =$	aggregate,			
	$x + 0{\cdot}15\,x =$	100 parts,			
and	$x =$	86·95 parts . .		=	aggregate.
Mortar in excess of interstices	=	13·04	„ . .	=	15 per cent. of aggregate.
		99·99	„		

			Parts.
Interstices (to be filled with mortar)	= 86·95 × 0·30 .	=	26·08
Mortar in excess of interstices	= 86·95 × 0·15 .	=	13·04
	Total mortar required .	=	39·12
To find cement and sand, add $\frac{1}{3}$		=	13·04
		7)	52·16
			7·45
			2
Cement, 1 part		=	14·90
Sand, $2\frac{1}{2}$ parts		=	37·25
Aggregate		=	86·95
			139·10

If, instead of fixing the quantity of mortar to be used certain ratios, such as 1 part of cement, 2 parts of sand, and 6 of stone, are fixed, it is necessary to determine whether such ratios allow sufficient mortar, and if this were done such ratios as 1 part of cement, 2 of sand and 6 of broken stone would probably not be specified in connection with good work.

(3) Suppose ratios of 1 part of cement, 2 parts of sand, and 4 of broken stone, having 48 per cent. of interstices are selected, and it is required to know how much cement, sand and stone are used in making 100 parts of finished concrete.

If x = cement, $2x$ = sand, $4x$ = stone:

$$\text{Mortar} = \frac{(x + 2x)\,3}{4} \quad \ldots\ldots \quad = 2\cdot25\,x$$

$$\text{Interstices} = 4x \times 0\cdot48 \quad \ldots\ldots \quad = 1\cdot92\,x$$

$$\text{Mortar in excess of interstices} \quad \ldots\ldots \quad = 0\cdot33\,x$$

Aggregate.		Mortar in Excess of Interstices.		
$4x$	+	$0\cdot33x$	=	100 parts,
		$4\cdot33x$	=	100 „
		x	=	23·09 parts cement,
		$2x$	=	46·18 „ sand,
		$4x$	=	92·36 „ stone.
				161·63 parts.

In this case, the amount of mortar in excess of the interstices is 8¼ per cent. of the aggregate.

The various proportions of any kind of concrete may thus be derived from the necessary data.

(*Students' Paper No. 395.*)

"Cooling-Reservoirs for Condensing-Engines."

By Harold Wood Barker, Stud. Inst. C.E.

In cases where a constant supply of water sufficient for condensing is not to be obtained, or where factories are entirely dependent on the town's mains for a supply of condensing-water, means are necessary of storing and cooling. The Author proposes to describe the methods of construction for the reservoirs usually adopted for this purpose, and, from comparison of the sizes of several examples with the HP. for which they were used and the temperatures and rate of cooling in them, to deduce the size necessary for any given power. The reservoirs which were investigated are those of worsted mills in the neighbourhood of Bradford.

The reservoir, if possible, is arranged near the engine and boilers, and at such a level with them that the water from the condenser or hot well will run back to the reservoir. This is not always practicable, and sometimes a special pump has to be used to lift the water back to the reservoir. If the water be not more than about 20 feet below the condenser, and if the condenser be of the injection type, the vacuum in the latter will raise its own water. This height, however, depends on the temperature of the water. In good practice it is not considered advisable to lift through more than 12 feet to 14 feet in this way.

If the water in the reservoir be the only water at hand, or if it be undesirable that water be used from the mains, the boilers are generally placed at such a level that water will run from the reservoir into them; for when the boilers have been emptied, say for cleaning or repairs, no steam will be available for working a pump; or, if this be not possible, a tank of sufficient capacity to fill the boilers is kept full of water at some height above them. The level and site of the reservoir, however, in actual cases, is found to depend almost entirely on its position with regard to the surrounding buildings and the nature of the ground about the works, and cannot always be arranged to suit all these desirable

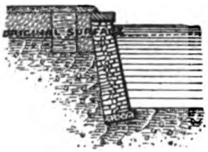
conditions. When possible a site where clay is present is chosen, as the cost is materially increased when clay has to be brought from a distance for puddling, or when concrete is used instead.

In order to promote rapid cooling, the surface of the reservoir should be as exposed as possible, that the wind may have free access to it. Hence the reservoir, when possible, should be kept clear of buildings and trees; high fence-walls should not surround it closely, and the banks should not be higher than is necessary above the water-surface.

The level of the reservoir should be such as to collect the maximum amount of rain-water which falls on the adjoining land, and in the case of large works which cover an extensive area the rain-water which falls on the roofs is generally discharged into it. This is a very welcome addition when the water evaporated in the reservoir has to be replaced by that from the town's mains.

Reservoirs in Solid Clay.—It sometimes happens, in the Bradford district, that the site of the reservoir is on a stratum of clay, in which case little has to be done besides excavate, level the bottom, and pitch the slopes or form a retaining-wall, bringing a puddle-wall up from the solid clay where the surface is raised by an embankment, *Fig. 1.* Great care, however, has to be taken to discover that the clay is perfectly good, and that there are no seams of porous material left without puddling.

Fig. 1.



Scale, $\frac{1}{16}$ inch = 1 foot.

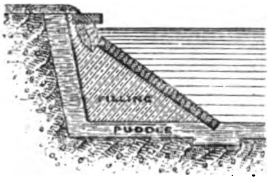
The cost of construction of this type, which requires the least labour, from a mean of four, is 1·18*d.* per cubic foot of water capacity.

Reservoirs with Puddled Bottom and Sides.—The greater number of cooling reservoirs in the Bradford district fall into this division. The depth must not be greater than that of an adjacent water-course or drain, otherwise it cannot be emptied without the aid of a pump. Usually the depth varies between 4 feet and 8 feet, and it is economical to excavate to such an extent that the excavated material will just suffice for the embankments. A thickness of 12 inches to 24 inches of puddle, depending on the character of the subsoil, is usually allowed over the bottom of the reservoir, and the puddle-core or wall is usually between 18 inches and 24 inches thick, depending on the depth of the reservoir. In some cases the puddle-wall is battered, as shown in *Fig. 2*, in others it is stepped, as in *Fig. 3.* The amount of excavation is lessened if this be the case.

The puddle-wall is worked into the bottom layer, and brought

up to the level of the coping. The embankment is generally sloped on the inside to a slope of about $1\frac{1}{2}$ to 1, and on the outside about 2 to 1, *Fig. 3*. The puddle-wall is taken up to the level of the coping and is then covered with 9 inches to 12 inches of earth or protection from sun and frost. The inner slope is pitched with rubble, laid by hand, broad edge upwards, and the interstices underneath are filled with ballast gauged through a 2-inch ring.

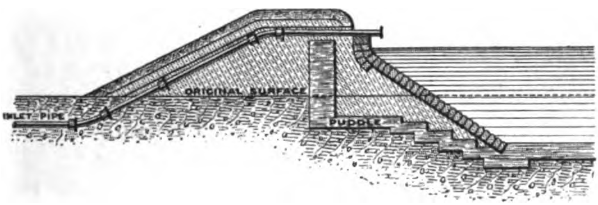
Fig. 2.



Scale, $\frac{1}{16}$ inch = 1 foot.

At a distance of about 1 foot below high-water level the rubble is thickened, set in hydraulic mortar, and curved up (as shown in *Figs. 2* and *3*) to about 6 inches above the surface of the water, to receive the stone coping. This gives a better finish for the coping than if the pitching were continued straight up, and is a more solid construction to withstand the wash of the water. It has also occasionally happened that rats have bored holes into the embankment, just about the water-line, with serious results to the puddle, and this the walling will prevent. The outer slope is grassed for the protection of the embankment. The embankment at the top is, generally, about 8 feet or 9 feet wide. Between the 14-inch walling just mentioned and the puddle-core there are, usually, about 12 inches to 18 inches of filling. The puddle-core is about 2 feet thick, and beyond this there are

Fig. 3.



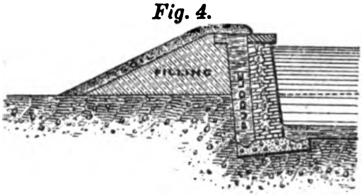
Scale, $\frac{1}{16}$ inch = 1 foot.

3 feet or 4 feet of filling for its protection and support before the outer slope commences. Greater capacity is obtained for a given area and depth if the sides of the reservoir be walled, *Fig. 4*. A rubble-wall, faced with coursed wall-stones about 30 inches thick at the bottom and battering to about 24 inches at the top, is built in hydraulic mortar on a broad footing of cement concrete; the latter, resting on a perfectly solid foundation

and projecting on each side of the wall, is notched to form a good key for the puddle, which is worked over it. The wall is almost perpendicular, a slope of about 18 inches in a depth of 8 feet being found sufficient if the ground behind be solid, and between it and the latter a puddle lining about 18 inches thick is worked, resting, as stated, on the concrete footing, and lapped at the top on to the solid ground.

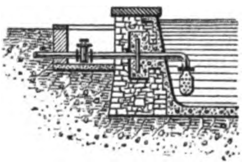
The cast-iron pipe to the condenser passes through the embankment or wall, and is taken well below the surface so as to withdraw the colder water, but it is kept 18 inches to 24 inches clear of the bottom, lest mud should be drawn down the pipe. To prevent the water following the pipe into the embankment, one or more flanges are fixed or cast on the pipe, about 2 feet to 3 feet diameter, and are imbedded in the puddle, the thickness of which is increased. The pipes are only jointed in the embankment when it is unavoidable, because, in case of leakage at the joints, which are liable to be strained by unequal settlement of the embankment, it is a very difficult and inconvenient matter to get at them for repairs, and necessitates emptying the reservoir. For this reason a retaining-wall is preferable to an earthen embankment at this point, through which an ordinary 9-foot length of pipe will pass with the joints outside the wall, *Fig. 6*. This pipe through the embankment is generally strengthened by making the metal thicker. The end of the pipe is fitted with a short perforated length of pipe called a "snore" pipe, *Fig. 5*, of somewhat greater diameter, to prevent large solid bodies entering and being carried to the condenser.

Fig. 4.



Scale, $\frac{1}{12}$ inch = 1 foot.

Fig. 5.



Scale, $\frac{1}{12}$ inch = 1 foot.

If the condenser be at a higher level than the reservoir, and the water has to be lifted, then the pipe is frequently taken over or through the bank, just above the water-line. A retaining-valve, of the ordinary india-rubber flap type, is fixed in the pipe above the water-level (so as to be accessible), to insure that the pipes are kept full of water when the engine is not working. Otherwise, difficulty may be experienced in starting if any of the joints admit air. Sometimes the valve is placed near the snore-pipe, well below

the surface. In this case the pipe is brought above the water-level, so that a joint may be reached when the vertical piece of pipe and the valve require removing for examination or repair of the valve. A sound argument, however, for taking the pipes through the bank in preference to over it, even if the condenser be at a higher level than the reservoir, is that they may be taken horizontally until beneath the condenser, and the water lifted vertically through the necessary height. The pipes are thus kept full of water, and, although the lift is in each case the same, yet in the latter the length of pipe through which the water is lifted is shorter and less air is to be pumped out on starting the engines. This is especially the case if the engine be some distance from the reservoirs.

A valve is necessary at the reservoir end of the pipes to shut the water out when required. This is often placed outside the reservoir, and when this is the case should be placed as close to the bank as possible. If the surface of the ground be level with the reservoir a well or area is constructed so that the valve may be easily reached. Should a pipe in the bank fail, however, owing to settlement and other causes, it could not be easily stopped, and the water leaking into the embankment might cause serious injury to the puddle. Hence it is a much better plan to have the valve in the pond itself. The varieties of valve most commonly used are:—(1) A simple slide-valve, *i.e.*, a sluice-valve sliding over the end of the pipe; (2) a clack or flap-valve; (3) a hinged sluice-valve; (4) a double-faced sluice-valve. The latter is by far the best, as a snore-pipe can be fitted. In the other types, should any large object become fixed in the entrance of the pipe the valve could not be shut. The second and third types are rarely used now and are not to be recommended.

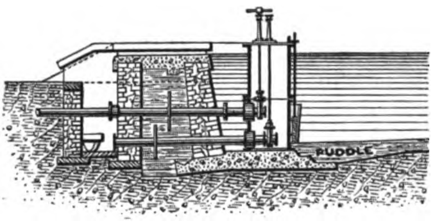
The first three may be worked from the embankment by having the valve fixed on the slant at the end of the pipe and the spindle brought up parallel with the inner slope. For the double-faced sluice-valve a platform or gantry is constructed long enough to clear the foot of the inner slope from which the spindle can descend vertically to the valve beneath.

A much better arrangement for the valves, well known to water-works engineers, but only recently introduced into the best mill practice, is a tower or well brought up above the water-level, in which the injection- and let-off valves are placed, *Fig. 6.* A simple wooden sluice is provided which can be easily lowered and the water in the tower run off. By this means the valves and snore-pipes are easily accessible in case of failure or choking. In the

old arrangement, without a valve-tower, the water in the reservoir had to be let off in order that the valves might be reached, which, apart from the cost of refilling—and this, when town's water has to be used, is a matter of some importance—would mean considerable loss to the proprietor of the mill owing to the suspension of all work until the repair was effected.

The tower is placed at that part of the reservoir which is nearest to the engine-house. The example shown in *Fig. 6* was formed of two cast-iron cylinders 3 feet 6 inches diameter and of $\frac{5}{8}$ inch metal, bolted together with a flanged joint. The lower one rested on a foundation of concrete 18 inches thick, which projected 3 feet 6 inches beyond the tower, and was stepped or notched for the puddle which covered the bottom of the reservoir. In this lower half of the cylinder an opening was formed with faced flanges and guides for the wooden sluice. An iron rod from the latter passed through an eye at the top of the tower, which also formed the fulcrum for the lifting lever. The top of the cylinder was covered with cast-iron plates, to which were fixed two cast-iron pillars through which the spindles from the let-off and injection-valves passed. These were worked by a key in the form of a cross. A gangway formed of cast-iron bearers and plates led from the embankment to the tower. The cost of a cast-iron tower of this kind, including gangway, floor-plates, &c., for a reservoir 8 feet to 10 feet deep is between £40 and £50.

Fig. 6.



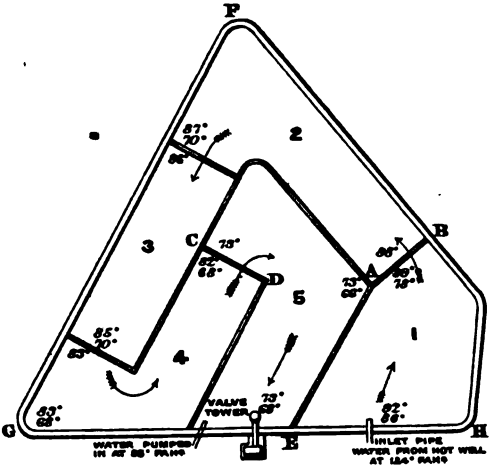
Scale, $\frac{1}{12}$ inch = 1 foot.

The hot water from the condenser is usually delivered by open cast-iron troughs—so that it may be cooled as it travels—to that part of the reservoir most remote from the injection-pipe. The actual loss of heat, however, in these troughs is far less than is generally supposed. It was found that in a trough 2 feet 6 inches wide, 7 feet deep, and falling $1\frac{1}{2}$ inch in length of 80 feet, the temperature fell 2° F. But the temperature of the water was 146° F. Had it been at a lower temperature the loss of heat would have been even less. A brick or concrete channel is sometimes used, but is less efficient in cooling than the cast-iron troughs carried on piers, where the air can have free play on every side of it. Cast iron is also a very much better conductor of heat.

Very often at the point where the water leaves the troughs another opportunity is taken of reducing the temperature. The last few lengths of trough are carried over the water and perforated, and through these holes the water trickles in many small streams. Another method is to discharge the water on to a cascade, or series of steps, on which the water is thoroughly broken up before entering the reservoir. This cascade may be arranged to advantage under the perforated length of trough.

When the engine-house is at a considerable height above the reservoir the water is sometimes discharged on to a wooden framework constructed over the water-surface, on which are placed cross-timbers carrying smaller pieces, branches of trees, slates, or anything suitable for breaking up the water and impeding its descent, and prolonging its contact with the cooling action of the air. A centrifugal distributor is sometimes used, by which the water is sprayed over the surface. In the reservoir itself artificial means are sometimes taken of abstracting only the coldest water for injection purposes. When two or more reservoirs are adjacent the water is taken from the bottom of one where it is coldest and delivered on to the surface of the next.

Fig. 7.

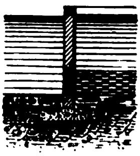


Scale, 1 inch = 80 feet.

A further application of this arrangement, which has lately been brought into use, is to construct brick partitions or guide-walls in the reservoir, *Fig. 7*. By properly planning these the water is made to pass round the reservoir in the most circuitous way, and by making the openings in the lower courses of the cross-walls, only the coldest water is allowed to travel from one compartment to another, the hot remaining at the top until sufficiently cooled. Consequently a greater difference is obtained between the maximum and minimum temperature of the water in the reservoir, and colder water is available for the condenser.

Fig. 7 is a plan showing how these guide walls were arranged in a triangular-shaped reservoir, and *Fig. 8* is a section of the cross-walls showing the open spaces in the brickwork. The latter was 9 inches thick, and was built in lias lime mortar on a cement concrete footing. The water from the hot well was delivered into the compartment marked 1, and was compelled to travel through the cross-wall, A B, and divisions 2, 3 and 4 before passing through the final cross-wall, C D, into the last compartment 5, in which the valve-tower was situated. The temperature of the water in degrees Fahrenheit at each side of the cross-walls is shown for each compartment, the bottom temperatures being placed immediately below the surface temperatures. There is a gradual decrease in the temperature, as the water circulates, until the last cross-wall is reached, when there is a sudden drop of 9° between the surface temperatures on each side of the wall. This was owing to the fact that a quantity of cold water at 55° was being pumped into the last compartment. It is unfortunate that such was the case, as the influence of the guide-walls cannot be so accurately judged, at least in the final compartment. For in the others the fall in temperature is more gradual, and does not seem to have been much affected. Brick being a bad conductor of heat, 20° difference in temperature was observed on opposite sides of the cross-wall A E, which formed the division between the hottest and coldest compartments. The greatest difference between surface and bottom temperatures of the water in any one compartment was 18°—in the second; whilst the difference between the maximum and minimum temperature of the water in the whole reservoir was 26°. Guide-walls remove the necessity of a great length of open cast-iron troughs to carry the water to that part of the reservoir most remote from the injection-pipe, and are little, if any, more costly. The injection- and delivery-pipes may be in adjacent compartments. It is important that these walls should not project much above the surface of the water or the wind will not have free play, and the rate of cooling will be decreased.

Fig. 8.



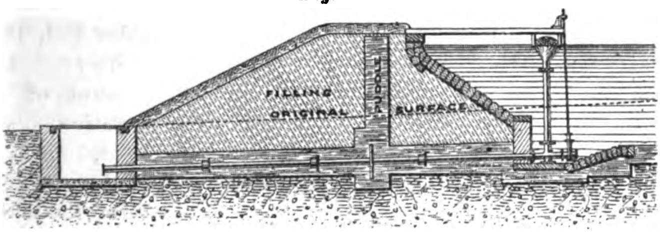
Scale, $\frac{1}{10}$ inch = 1 foot.

The reservoir floor is made to fall slightly from every side to some particular point near the embankment at which a shallow well or "sump" is made, and from this the emptying pipe takes its water, *Fig. 10*. As a rule it is arranged at that part of the reservoir which is nearest to some water-course or drain into which the water may be discharged. The same precautions are taken in fixing the pipes in the embankment, and the same

arguments may be used in favour of the let-off valve being inside the reservoir, as in the case of the injection-pipe. This let-off pipe should be of large diameter, so that the reservoir may be quickly emptied. This is important at factories where the mud has to be removed from the bottom during week ends or short holidays. If there be a valve-tower in the reservoir the let-off pipe is brought into it, *Fig. 6.*

In all cases where the reservoir is liable to sudden rises of level an overflow of ample size should be constructed. *Fig. 6* shows in section an overflow arranged over the retaining wall near the valve-tower discharging into a well or eye from which a drain led to the nearest water-course. The overflow was formed of concrete overlapping the outer face of each wall and notched into the puddle-core as shown. *Fig. 9* shows how the discharge pipe can be used as an overflow by fixing to it on the embankment side of the valve a vertical pipe with a funnel at the top level with the

Fig. 9.



Scale, $\frac{1}{16}$ inch = 1 foot.

water surface when the reservoir is full. A grating, raised in a convex form as shown, is placed over the funnel to prevent floating material being washed down and stopping up the pipe. This arrangement is cheaper than an overflow constructed of masonry, but is seldom used.

When there is a constant overflow, as in the case where a small stream enters the reservoir, the discharge from the hot well may be run into a tank, from the surface of which the water which is in excess may be run off. In this way the hottest and most greasy water is got rid of, and only the cooler and cleaner is returned to the reservoir.

A settling-tank is sometimes interposed where the stream enters the reservoir in which any matter that is in suspension may be deposited. The reservoir is thus prevented from being silted up with sand or mud. *Fig. 10* is a section of a settling-tank built of brickwork in cement 14 inches thick, resting on a cement-concrete

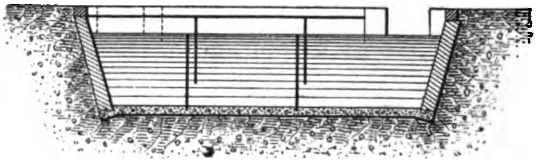
bottom 8 inches thick. Iron plates are arranged across the tank as shown to check the flow of water along the surface and assist deposition.

The cost of the puddled reservoir is found to vary between 1·5*d.* and 2*d.* per cubic foot of water capacity, an average of four being 1·71. It is reduced if the site be excavated to such an extent that the excavated material will just suffice to form the embankment around. The excavation is thus reduced to a minimum, and there is no surplus material to be carted away. This last item has been found to raise the cost of excavation from 1*s.* to 2*s.* 6*d.* per cubic yard, or even more.

A retaining-wall similar to that shown in *Fig. 3* is found to be about three times as costly as a pitched slope (*Fig. 2*). But the cost per cubic foot of water capacity is not increased to the same extent, on account of the greater capacity which the walled sides give for a given area.

The reservoir shown in *Fig. 8* was excavated over the whole area, but on the sides F G, G H, where the amount of excavation was least, an embankment was formed, which raised the water-level to a maximum height of about 4 feet above the original surface of the ground. The bottom was good stiff, yellow clay, but was found to be seamy and streaked with vegetable matter, and was therefore cut up with the tool and worked into puddle to a depth of 12 inches. The water-surface was 19,143 square feet, and the water capacity 127,000 cubic feet.

Fig. 10.



Scale, $\frac{1}{16}$ inch = 1 foot.

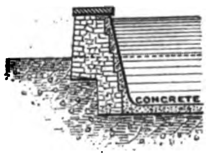
The total cost of the reservoir shown in *Fig. 8* (excluding valve-tower and pipes) was—

	£
Excavation	247
Puddle	125
Concrete footings	117
Walling	243
Coping	81
Guide-walls	99
Slopes, forming and soiling	8
	£920

Cost per cubic foot of water capacity, 1·7*d.*

Concreted Reservoirs.—When clay cannot be easily obtained for making a watertight reservoir concrete is often used, *Fig. 11* and *Fig. 6*. The site is excavated to the required depth, and a retaining-wall of large rubble in hydraulic mortar is built on a good concrete footing. On the water side of this retaining-wall a step of 3 inches is formed about every 18 inches, which gives a good key and support for the concrete lining. The mortar joints are also left open for about 1 inch from the face for the same purpose. These walls are then faced with a coating of fine cement-concrete of good proportions, worked to a smooth face with all corners well rounded. The minimum thickness is 3 inches. A delfstone coping about 6 inches thick is placed on the top; and the bottom of the reservoir is formed of a layer of cement concrete about 8 inches thick, in two layers—the lower one, about 6½ inches thick, consisting of 4 parts of broken stone or clean hard burnt clinker through a 1-inch gauge to 1 part of best Portland cement, and the upper face about 1½ inch thick through ½-inch gauge and in the proportions of 2 to 1.

Fig. 11.



Scale, $\frac{1}{16}$ inch = 1 foot.

A concreted reservoir can be elevated partly above the natural surface of the ground, without much trouble and without much increase of expenditure, by making the retaining wall heavier, *Fig. 4*. In this way the amount of excavation is reduced, and the water-level can be raised to any desirable extent.

The costs of two of these concreted reservoirs were 2·2*d*. and 4·2*d*. per cubic foot of water capacity, or a mean of 3·2*d*. The somewhat large difference between the two is due to the fact that 2*s*. 3*d*. per cubic yard had to be paid for the excavation for the second, and that the amount of excavation was large. No embankment could be constructed, as it was necessary that the pond should be slightly below the original ground surface. If the excavation be taken at an average price of 1*s*. per cubic yard the cost would be reduced to 3·4*d*. per cubic foot of water capacity. The concreted cooling reservoir, then, is the most expensive of the three types. The cost is 1·49*d*. per cubic foot of water capacity greater than that of the puddled reservoir. This figure may be taken as representing roughly the extra cost due to the substitution of cement-concrete for puddle, and to the extra thickness of walling where the water-level is raised above the original surface of the ground. The cost of the concreted reservoir is also 2·02*d*. per cubic foot of water capacity greater than the

mean cost of the reservoir in solid clay, and this represents the cost of covering the sides and bottom with concrete and, as before, the extra thickness of walling.

The difference in cost of the first two classes is but slight, the extra cost due to puddling being only about 0·53*d.* per cubic foot of water capacity.

The cost of the concreted reservoir mentioned above as being 4·2*d.* per cubic foot of water capacity is given in detail below. It was rectangular in shape, entirely excavated, had no embankment, and the depth of water averaged about 7 feet 6 inches, the surface area of water was 6,111 square feet, and the water capacity 43,390 cubic feet.

	£
Excavation	262
Concrete	291
Walling	141
Coping	40
Guide-walls	28
	£762

Size of Reservoirs.—It is evident that the size of the reservoirs depends upon the horse-power to be dealt with (or more strictly, the number of thermal units given to the condenser) and the hours of working, and also, as will be seen from the experiments given later, the favourableness of the situation with regard to cooling. In the case of engines working night and day, the engine runs continuously from 6.30 A.M. on Monday to 1 P.M. on Saturday, with only short stoppages for meal hours. The power exerted at night, however, is in some cases considerably less than that during the day. The following results have been calculated on the day power. Of the three reservoirs taken the capacities were found to vary between 99 cubic feet and 363 cubic feet of water per I.HP., giving an average of 255 cubic feet, while the water-surfaces varied between 18 square feet and 55 square feet per I.HP., the average being 32·4 square feet. In the case of the reservoirs which were used in the daytime only, seven were taken and gave the following results: Water capacity, 61 cubic feet to 351 cubic feet per I.HP.—average 198 cubic feet; water-surface, 13·5 square feet to 57·6 square feet per I.HP.—average 33·3 square feet. It will be seen, on comparing the average surfaces, that there is but little difference between the day working and the night-and-day working; but, in the case of the capacities, the latter is the greater.

The conditions of working the reservoir—which, of the second division (*i.e.*, day working), had alike the smallest capacity and surface, viz., 61 cubic feet, and 13·5 square feet per I.HP.—were more fully investigated, and it was found that these ratios were not sufficient for economical working. The particulars were taken during the month of July, in warm, still and sultry weather, when the rate of cooling is very low. Temperatures of the water in the reservoir were taken on the Monday and Saturday. The temperatures rose during the week, and on the Saturday noon the injection-water being used was at 119° F., and returned from the hot well at 148° F. By 6 A.M. on Monday the water had only cooled to 91° F. The mean temperature of the air in the shade during this period was 62° F. The reservoir was not favourably situated for rapid cooling, a wall several feet high surrounding it, and there were buildings on two sides.

Another reservoir was selected for experiment—this time supplying condensing-water for triple-expansion engines working with 160 lbs. per square inch boiler-pressure, and indicating about 1,350 HP. during the day—and also for a compound at about 120 lbs. per square inch boiler-pressure, and indicating about 300 HP. during the night. There were two reservoirs. The water from the hot well was carried in cast-iron troughs to the most distant one, from the bottom of which, at the opposite end, the coldest water was taken and delivered on to the surface of the second, the injection-pipe being at the contrary end and near the bottom. The reservoirs were sheltered on the north side by the mill, but were quite exposed on the other sides. This reservoir was the smallest of the first division. Its capacity was 99 cubic feet per I.HP., and its surface 18 square feet per I.HP. In similar weather to that in which the first experiment was made and most unfavourable to rapid cooling, the temperature of the injection-water on Saturday noon was 88° F.; and of the hot well 124° F. And on Monday, at 6 A.M., the injection-water was at 79° F., and the hot well 117° F. The mean temperature of the air in the shade, while the reservoirs were cooling, was 61° F.

It may be safely assumed that at no other time during the year would the temperature of the injection-water much exceed 88° F. During the winter months it would probably be some degrees lower. At this temperature, and with the hot well at 124° F., the weight of injection-water used was about twenty-nine times the weight of the feed-water, and with colder injection-water less would be used. With a cooling surface, therefore, of 18 square feet, and a capacity of 99 cubic feet per I.HP., the temperature of

the condensing-water may be said to be fairly satisfactory. It is not advisable, however, that these figures should be reduced.

It must be remembered that the steam consumption per I.HP. was low, owing to the economical type of engines and the high boiler-pressure, and also that the HP. during the night was rather less than one quarter of that during the day. With less modern engines and boilers, or with a greater night-power, the surface should be increased. Seeing, then, that the steam consumption per I.HP. per hour and the heat rejected by different engines are variable quantities, it is not strictly true for all cases that 1 I.HP. requires such a surface and capacity of cooling-reservoir. In order to ascertain the ratio of the surface and capacity to the heat rejected, the water flowing in the cast-iron troughs from the hot well was gauged, and from this was subtracted the approximate feed-water. The condenser was of the injection type. The rise in temperature of the injection-water being known, the thermal units absorbed by the condensing-water were easily calculated, and it was found (taking the day-power only) that there were 1·8 square foot and 9·9 cubic feet per 1,000 thermal units per hour. This would mean that about 558 thermal units would have to be dissipated per square foot per hour during the daytime in order that the temperature of the water in the reservoirs might not be raised. But from the tests taken it was found that the mean temperature of the water in the reservoirs was raised (by night and day working) during the week from 76° F. on the Monday to 95° on the Saturday, an increase of 19° F. Hence the rate of dispersion of heat must have been something less than 558 thermal units per square foot per hour. The Author arrived at this figure approximately as follows: The heat rejected by the triple-expansion engines during the day and by the compound during the night was measured from the water flowing in the troughs, as mentioned above. From this total was subtracted the quantity of heat required to raise the temperature of the water in the reservoirs the amount before mentioned, the remainder being the quantity dissipated. This gave an average rate of dispersion for night and day during the week of about 290 thermal units per square foot per hour. The mean surface temperature of the reservoirs was 77° F. at 6 A.M. on Monday, and 105° F. at noon on the Saturday. The mean temperature of the air in the shade during the week was about 61° F.

It may be well here, perhaps, to examine briefly the conditions which affect the rate of cooling. When water is in contact with air at a lower temperature, heat is abstracted from the water by

the following processes: (1) Radiation, (2) Conduction, (3) Convection, (4) Evaporation.

Radiation.—Heat is dissipated into space without sensibly raising the temperature of the air. The quantity of heat emitted increases in some proportion with the difference in temperature of the air and the water, but more rapidly than the simple proportion as the difference increases. Clearness of atmosphere is favourable to radiation; hence, the more exposed the reservoir, the less is radiation impeded by clouds of vapour from the water.

Conduction.—The low conductivity of liquids and gases is counterbalanced to some extent by convection. Hence, here again exposure to wind is of great service.

Convection.—Conduction and convection act in conjunction. The warm surface-water parts with some of its heat to the air in contact with it. The latter, if the weather be still, rises, or if windy, is carried away, and colder air takes its place, while the water sinks, giving place to warmer. Again, the heat is conducted from the warmest water at the surface downwards through the water to the bottom and sides of the reservoir, but the amount dissipated in this way is probably very small. Flow of heat from the water to the air is proportional to the difference in temperature between the two. Hence cold weather is favourable to both radiation and conduction.

Evaporation.—In none of these former processes is water lost, but in the case of evaporation, the loss of water becomes considerable. Indeed, when the water is being cooled almost entirely by evaporation, the amount of water lost very nearly agrees with the steam consumption of the engine. The conditions of weather favourable to evaporation are: (1) dryness of air, (2) low atmospheric pressure, (3) high temperature of water and air, (4) renewal of air in contact with water. Evaporation can take place at any temperature; but during the weather which satisfies to the fullest extent these conditions evaporation will be most rapid. Cooling is slow in damp, calm weather; and rapid in dry, breezy weather. According to Dr. Dalton's law, when the atmosphere is perfectly dry, the rate of evaporation is proportional to the pressure of the vapour due to the temperature of the water. But when vapour is present in the air—as it always is in varying proportions—the pressure of this vapour must be deducted from that of the vapour due to the temperature of the water. The resultant pressure is the active evaporating force. And Dr. Dalton found by his experiments that, whatever be the temperature of the air, with the same evaporating force the same rapidity of

evaporation is obtained. Yet it is said, in spite of this, that water is evaporated more rapidly when in contact with warm air than with cold. The increase being probably due to the reflex action of the heat given up to the surface-water by the air.

Evaporation is increased by wind because the vapour is carried away by the wind as soon as it is generated and a fresh supply of comparatively dry air takes its place. The actual surface in contact with the air is also increased by the ripples or waves that are formed. Dr. Dalton found that with perfectly dry air the rate of evaporation was influenced by wind to the following extent:—

Evaporation for still air	1·00
For a gentle wind	1·28
For a brisk wind	1·57

That an increase in the temperature of the water is followed by an increase in the rate of cooling was proved by experiments carried out by the Author. The temperatures of the two reservoirs already mentioned were taken (one reservoir being at a higher temperature than the other), and after a period of 15 hours they were again taken. The mean of the surface temperatures taken at the beginning and the end of this period, during which cooling was going on, was 90° for the one and 77° for the other, and the rates of cooling were respectively 229 and 162 thermal units per square foot per hour. Thus with an increase in the mean temperature of the surface-water of 17 per cent., the rate of cooling was increased 41 per cent. The mean temperature of the air during the 15 hours was 56°. The atmosphere was damp with short showers, and a gentle breeze was blowing.

Another reservoir, tested on a different occasion with a mean surface temperature of 105°, only cooled at the rate of 191 thermal units per square foot per hour. But this experiment was made in very close still weather, and the reservoir was shut in by walls. The mean temperature of the air was 62° F.

From the experiments made, therefore, it has been shown that the rate of cooling is not constant. In most unfavourable conditions of atmosphere and situation, the rate of cooling may be reduced to about 190 thermal units per square foot per hour, even if the surface temperature of the water be high, while in similar atmospheric conditions, but with more free exposure, 290 thermal units may be dissipated per square foot per hour. On the contrary, at the most favourable times it is very probable that about 600 thermal units per square foot per hour may be dissipated.

From the experiments given it has been shown that the surface of a reservoir should not be less than 1·79 square foot per 1,000 thermal units per hour if a moderate amount of condensing-water is to be used. This will mean that a triple-expansion engine using, say, 13 lbs. of steam per I.HP. per hour requires a minimum of 25 square feet of cooling-surface per I.HP. A compound engine using, say, 16 lbs. of steam per I.HP. per hour requires 31 square feet, and a single-cylinder engine using 20 lbs. requires 39 square feet per I.HP. These are minimum values, and where possible should be increased, especially if the engine works night and day with the same load, or if the situation be very closed in.

The capacity, as already shown, should not be less than 9·9 cubic feet per 1,000 thermal units per hour; and this for the three types of engines mentioned would be respectively 138 cubic feet, 171 cubic feet, and 214 cubic feet per I.HP. But the greater the depth the better, so long as the surface is ample, for then the difference in temperature between water at the surface and water at the bottom is increased, and thus colder water is obtained for the condenser. It was found on one occasion that in a reservoir 146 feet by 75 feet, in which the water was about 6 feet 9 inches deep, a difference of 34° F. was obtained between the maximum surface temperature and the minimum bottom temperature.

If the surface of the reservoir be limited, and night cooling has to be relied on to some extent, the depth may be profitably increased, thus giving a larger capacity of water to receive the heat from the condenser during the day and consequently causing a smaller rise in temperature.

The Paper is accompanied by tracings from which the *Figs.* in the text have been prepared.

OBITUARY.

GEORGE JOHNSTONE DARLEY, youngest son of the late Henry Darley, M.D., of 7, Kildare Street, Dublin, was born in the parish of Blackrock, near Stillorgan, co. Dublin, on the 26th September, 1822. He was educated first at Blandford, Dorsetshire, under Dr. Wyse, and subsequently at Merchiston Castle Academy under Dr. Chalmers. In 1840, at the age of eighteen, he became an articled pupil of Mr. I. K. Brunel.[1] The extensive and varied works then being carried out by Mr. Brunel afforded many opportunities for the acquisition of professional knowledge and experience, and of these Mr. Darley availed himself to the fullest extent. He was subsequently engaged as Assistant Engineer on the Cheltenham and Great Western Union and the South Devon Railways, and afterwards as Resident Engineer on the Vale of Neath Railway, the Briton Ferry Docks, and the West Somerset Railway; on the last, from its commencement to completion, first under Mr. Brunel and subsequently under Mr. Robert Pearson Brereton.

Mr. Darley prepared a design for the Great Exhibition building of 1851, for which he was awarded a medal and certificate.

In the spring of 1864 Mr. Darley joined his relatives, Messrs. Guinness and Mahon, in Dublin in their land agency business, and from 1869 he carried on that business at Ballinrobe, co. Mayo. In 1874 he entered into partnership with Mr. Burke, practising at Ballinrobe as Burke and Darley until 1893. He then retired and took up his residence at his grandfather's old home, the Grange, Stillorgan, where there was much to occupy his time and interest him in works of restoration and improvement. These he had the gratification of completing prior to his death, which took place there on the 17th January, 1898.

Mr. Darley's business as a land agent comprised also some purely engineering works. In 1875 he designed and carried out for Lord Ardilaun, the pier and harbour works, and approach roads, &c., at Lisloughrey on Lough Corrib, near Cong. His occupation was of a hazardous nature in consequence of the disturbed state of Ireland, particularly in the west where he

[1] Minutes of Proceedings Inst. C.E., vol. xix. p. 169.

resided. The danger to the life and property of landlords and their agents imposed a heavy mental strain on those exposed to it. Mr. Darley discharged his duties manfully through those trying years, with the knowledge that he might any day be the victim of a murderous outrage. The Government considered it necessary that special police protection should be given him, and quartered two constables at his residence and two at Ballinrobe to keep guard and patrol the roads he travelled. An old friend, who was visiting him and well knew the goodness of his nature, expressed surprise that one so beloved should need to be guarded. His reply was: "I fear no danger from those who know me, but murderous edicts go forth and plenty, probably 'lotted' from other parts, are ready to obey." Mr. Darley was most careful and reliable in all he undertook. He was a good mathematician, and during his railway practice he prepared useful and comprehensive sets of Tables for facilitating the setting-out of railway lines and curves. In disposition he was sincere, kindhearted and amiable, just, generous, and considerate towards all with whom he had relations.

Mr. Darley was elected a Member on the 2nd February, 1864.

Sir CHARLES HUTTON GREGORY, K.C.M.G., Past-President, who died on the 10th January, 1898, had been for some years what was called "The Father of the Institution," *i.e.*, the Member whose name had been longest on the roll; he having been elected a Graduate on the 13th February, 1838.

The name of the deceased brings down to the present day reminiscences of the time when engineering began to be treated, not merely as a practical constructive art, but also as a scientific study. And it may be useful, as a matter of history, to explain how this came to pass.

The Royal Military Academy at Woolwich had been long known as one of the most efficient educational establishments in the kingdom; and it happened that nearly a century ago its most important scientific office, namely, the professorship of mathematics, was filled by a man of high character and attainments named Charles Hutton, LL.D., F.R.S. Having the interest of his pupils much at heart, he prepared, chiefly for that establishment, but also for the general use of "all seminaries of learning," a "Course of Mathematics," which became much celebrated and used, having a more practical style, and far more general utility

than any other work upon the subject in the English language. It occupied three octavo volumes, and it went through several editions.

After Dr. Hutton's death in 1823, his place in the Woolwich Academy was taken by Olinthus Gregory, LL.D., a man also of considerable eminence in literary and scientific matters. He was a member of many learned societies in England and abroad, and he was Secretary to the Astronomical Society of London; and, as a qualification which brings him within the scope of this memoir, he was also an Honorary Member of the Institution of Civil Engineers.[1]

He edited a new edition of his predecessor's work, with corrections and improvements; but he did more. He saw that a book of this kind with some modification would be especially useful to engineers, who in that day, following the example of their great forerunners, devoted their attention chiefly to practical matters. He felt, therefore, "a desire to draw up an essay on the principles and applications of the mechanical sciences for the use of the younger members of the Institution of Civil Engineers." He spent some years on the preparation of this book, and it appeared in October, 1825, with the title:—

> "Mathematics for Practical Men: being a common-place book of Principles, Theorems, Rules, and Tables, in various departments of pure and mixed Mathematics with their most useful Applications; especially to the pursuits of Surveyors, Architects, Mechanics, and Civil Engineers."

and it was dedicated to "Thomas Telford, Esquire, President, and to the various Officers and Members of the Institution of Civil Engineers."

The book well carried out the idea of the Author, and it was the best if not the only good manual of theoretical instruction for engineers until the more modern principles were embodied in the great work brought out by Professor Henry Moseley in 1843.

The subject of this memoir was Dr. Olinthus Gregory's son, born at Woolwich on the 14th October, 1817; and the names given to him clearly manifest the respect which the father bore to Charles Hutton, as a predecessor in the promulgation of engineering science. The boy was educated at Totteridge, where he had a classical and mathematical training under the mastership of Messrs. Thorowgood and Wood, whose school at that time was the training home of many boys who were destined to become notable

[1] Minutes of Proceedings Inst. C.E., vol. ii. (1842), p. 12.

men. He, like many other youths, had in his mind a particular fancy—he wished to become a sculptor. Dr. Gregory did not discourage his son, but took him to the best adviser available—the sculptor Chantrey—when, after an interview, the latter found the aspirant to have powers which would fit him for a career widely different; and this view undoubtedly gave Dr. Gregory much satisfaction. He had opened his son's mind to mathematics and logic, and that training was specially suitable for an engineering career.

It was a favourite saying of Sir Charles Gregory in talking about his father, "I never knew my father do a wrong thing." And assuredly he did not do wrong when he apprenticed his son to Mr. Timothy Bramah, with whom the youth served his time to learn the business or craft of a millwright and engineer.

He was afterwards engaged as an Assistant Engineer under Robert Stephenson on the Manchester and Birmingham Railway; under James Walker on a graving dock in Woolwich Dockyard; and in 1840 he became Resident Engineer of the London and Croydon Railway, and carried out important works in the widening of that line, and the necessary alteration of bridges, &c., without interfering with the traffic of the railway. In 1841 [1] he designed and erected at New Cross the first semaphore signal of the well-known form that has since been universal on railways. His successful measures—as described in a Paper presented to the Institution in 1844,[2]—in dealing with some extensive and disastrous slips in the London clay which occurred in the New Cross cutting were both bold and original. He had also written "Practical Rules for the Management of a Locomotive Engine" [3]—believed to be the earliest handbook of the kind.

The Croydon and Epsom Railway was constructed under his direction, and in 1846 he succeeded Mr. Brunel as Chief Engineer of the Bristol and Exeter Railway, in which capacity he laid out and constructed several railways in the West of England.

In 1855 Mr. Gregory was appointed by the Government a member of the Ordnance Select Committee, an office which he held until 1859, when the Committee was reconstructed. He was for many years professionally connected with the General Post Office in the settlement, by arbitration, with railway companies of the rates of payments for mail service and in other matters.

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[1] Minutes of Proceedings Inst. C.E., vol. xxxviii. p. 204.
[2] *Ibid*, vol. iii. p. 135. [3] Library Inst. C.E.

He was a Juror in the Paris Exhibition of 1867, a member of the Small Arms Committee from 1870 to 1872, and of the Channel Tunnel Committee in 1882, also of the Royal Commission appointed to carry out the Colonial and Indian Exhibition. He laid out and reported upon many works in France, Italy, and Austria; notably the drainage of Lake Fucino in Italy; the construction of the Beziers and Graissesac Railway in France, which was commenced under his direction and from his design; and the preliminary work of the Wsetin and Silein Railway in Moravia, which was conducted by him. He also examined, and reported on the construction of the Grand Trunk Railway of Canada.

He was Engineer of the Somerset Central and Dorset Central Railways; Consulting Engineer of the Recife and São Francisco Pernambuco Railway in Brazil; the Ceylon Railway, first as Consulting Engineer for the Company, and ultimately, when the Railway was taken over by the Government, his appointment, in 1863, by the Government, as Consulting Engineer for the Railways of Ceylon, was the commencement of his work in connection with the Colonies, which brought out the results of his ripe experience. He more than once received the thanks of the Governor in Council for his valuable services to that Colony.

In 1871 he was appointed Consulting Engineer to the Government of Trinidad for Railways, and nominated engineers to make the necessary surveys for the determination of the proposed line from Port of Spain to Arima, in the Island of Trinidad, West Indies; and estimates were got out under his instructions for the laying out of the line on either of two gauges, which resulted in the adoption of the gauge, for this line, originally recommended by him—of 4 feet 8½ inches; various extensions have since been carried out under his direction.

At about this period he was invited to become Consulting Engineer for the Cape Government railways, and it having been determined by the Government of the Cape of Good Hope that their proposed lines should be made on the 3 feet 6 inches gauge, he accepted that condition, and designed rolling stock and permanent way, &c., suitable for the expected traffic, including a great increase in the weight of the rail proposed by the Cape authorities to 45 lbs. per yard for iron rails and 46½ lbs. for steel rails. This weight has since been increased to 60 lbs. per yard. He nominated a large staff for the survey and construction of these railways, most of which were carried out without the intervention of a contractor.

In 1883 he undertook the Consulting Engineership of the protected native States of Perak and Selangor, in the Straits Settlements, and settled the conditions on which these lines should be constructed, nominating a staff for each, and designing and superintending the construction of the rolling stock, fixed plant, &c., for each of the aforenamed railways, as well as of other colonial railways in reference to which he was consulted.

For a considerable period of his professional life, he was largely concerned in arbitrations, either as sole arbitrator, or as umpire. In this capacity he never had an award set aside. For his services to the Colonies he was made a Companion of the Order of St. Michael and St. George in 1876, and in May, 1883, a Knight Commander of that Order. He was also an officer of the Order of the Rose of Brazil, a distinction conferred upon him by the late Emperor Dom Pedro II. of Brazil.[1] He was one of the original Members of the Royal Colonial Institute, having joined as a Fellow in 1868, and he always evinced great interest in its work and progress. He was Captain Commandant of the 1st Tower Hamlets Engineer Volunteer Corps from 1861 to 1864, and was Lieutenant Colonel of the Engineer and Railway Volunteer Staff Corps, in due time being made a full Colonel, and receiving ultimately the volunteer long-service decoration. As an Engineer Volunteer Officer, he was, from his early associations and training, a most valuable officer. He acted as Aide-de-camp to the late General Sir Montagu McMurdo,[2] Inspector-General of Volunteers, on several occasions. He was an enthusiastic Freemason, and for many years held high office in grand lodge. He was also a Past-Master and Member of the Court of the Turners Company, and a member of the Athenæum and the Windham Clubs.

He was 21 years of age when he became a Graduate of the Institution. Seven years later, on the 18th February, 1845, he was elected a Member. In 1849 he became a Member of Council, and was annually re-elected until his elevation to the Presidential chair in 1867, a position which he held for two years. Some years later it was felt by his many friends scattered over the world, more particularly in the Colonies, where his connection had been fraught with such beneficial results to them, that his personality should be perpetuated on the walls of the Institution. This resulted in an excellent portrait in oils, painted by Mr. (now the Hon.) John Collier. The amount remaining from the subscriptions was found

[1] Minutes of Proceedings Inst. C.E., vol. cviii. p. 394.

[2] *Ibid*, vol. cxvii. p. 397.

to be sufficient to have an engraving, made by Mr. Charles A. Tomkins, sent to all subscribers, and the balance then left, amounting to nearly £106, was placed by Sir Charles Gregory to the credit of the Benevolent Fund of the Institution, to which he had been a generous subscriber from the commencement. He was fond of doing good, in the way of giving relief, by stealth, and never liked to be found out. Those who were in his confidence seldom heard of any specific act of charity of his, save through some acknowledgment, written or verbal, by the recipient.

His kindliness and courtesy were proverbial and unfailing. He was in many respects an exceptional man, characteristically exact in thought, act, and diction, and this gave an especial value to his words, and to his reports and other writings. He was a constant attendant at the meetings of the Institution for many years, and took an active part in its deliberations, whether on the Council or otherwise, as well as in the discussions. In the many appointments which he was called upon to make, and in which he acted with absolute impartiality, he had a happy method, in his interviews with candidates, of putting them at their ease; in feeling that they were talking with a friend they carried that thought with them into their work. In 1892 he took into partnership his friend and assistant, Mr. G. L. Eyles.

In 1894 he married Mrs. Fanny Stirling, the well-known actress, widow of Mr. Edward Stirling. The death of Lady Gregory took place in the following year.

SYDNEY HOWNAM HOWNAM-MEEK, born on the 23rd May, 1854, was the third son of the late Mr. Sturges Meek, at one time Chief Engineer of the Lancashire and Yorkshire Railway. After being educated at Cheltenham College he spent a few months in some mechanical engineering works at Rouen, and then served his time under his father. On the expiration of his pupilage he obtained some experience of contractors' work, first at Clayton West, and subsequently on the construction of the Ascot and Aldershot Railway. In 1877 Mr. Hownam-Meek entered the service of the Lancashire and Yorkshire Railway Company, and was Chief Assistant in the Permanent Way Department until 1881, when he was appointed Resident Engineer on the widening of the London and North-Western main line between Heaton Norris and Longsight. He also acted in a similar capacity on the Stockport Junction line, the goods yard at Edgeley, the

Denton and Dukinfield branch, and the Heaton Norris and Reddish widening.

In November, 1887, Mr. Hownam-Meek entered the service of the Manchester Ship-Canal Company, in which he remained until May, 1891, when, owing to the approaching completion of the works, a large reduction in the staff was made. He acted as Resident Engineer for the Company on the extensive works carried out for the diversion of the following lines of railway: the old Grand Junction Railway, which now forms part of the London and North-Western main line; the Birkenhead, Lancashire and Cheshire Junction Railway, belonging to the North-Western and Great Western Companies jointly and forming part of the Manchester and Chester Railway; and the Warrington and Stockport line on the North-Western system. Besides other extensive works these deviations included the construction of three large viaducts, two over the Ship-Canal and one over the River Mersey. The total length of the deviation railways under Mr. Hownam-Meek's charge was between 6 miles and 7 miles, and the embankments upon which they were raised, so as to provide a headway sufficient for the passage of large vessels at each crossing of the canal, were of exceptional magnitude.[1]

Mr. Hownam-Meek was next engaged for some years for the Great Northern Railway in testing iron bridges on that Company's system. His career, however, was prematurely cut short. After 48 hours' illness he died at his residence in Heaton Chapel, near Stockport, on the 30th January, 1898. He was elected an Associate Member on the 25th May, 1880, and was transferred to the class of Members on the 8th May, 1888.

PATRICK O'MEARA was born at Nenagh, co. Tipperary, in the year 1834. After being educated at the Jesuit College, Clongowes Wood, and at Queen's College, Cork, where he graduated B.A., he became in 1857 a pupil of Mr. W. R. Le Fanu,[2] under whom he was engaged on the construction of the Bagnalstown and Wexford Railway. In 1861 he went to Mauritius on the staff of Mr. Thomas Brassey,[3] who, in conjunction with Mr. G. E. Wythes[4] and Mr. James A. Longridge,[5] had undertaken the construction

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[1] Minutes of Proceedings Inst. C.E., vol. cxxxi. p. 21.
[2] *Ibid*, vol. cxix. p. 395.
[3] *Ibid*, vol. xxxiii. p. 246.
[4] *Ibid*, vol. xli. p. 232.
[5] *Ibid*, vol. cxxvii. p. 372.

of the Mauritius Government Railways, Mr. Longridge being the local managing partner and chief of the staff. Mr. O'Meara was Chief Assistant, and by his energetic and successful work gained high praise from his employers and from all who were associated with him.

On the completion of the Mauritius Railways, Mr. O'Meara was transferred in October, 1865, to India as one of the chief agents on Messrs. Brassey and Wythes' contract for the construction of the Delhi and Punjab Railway. From September, 1868, to July, 1870, he was engaged as district agent on Messrs. Brassey, Wythes and Perry's contract for the Chord Line of the East Indian Railway, on which some heavy works were successfully carried out. On both these works he was assisted by his brother, Mr. Thomas Francis O'Meara.[1] He then returned to England and was employed as Resident Engineer on the construction of the East Cornwall Mineral Railway, on the completion of which he went to Hungary, where he was engaged for Messrs. Wythes and Longridge in charge of the construction of the Francis Canal.

Early in 1876 Mr. O'Meara established himself in Natal, where he practised on his own account as an authorized Government Surveyor and as a civil engineer, designing and carrying out waterworks, tramways, etc.

He was also employed by the Colonial Engineer (then Captain A. H. Hime, R.E.) in making surveys and preparing information at Durban Harbour to furnish to Sir John Coode, for his visit of inspection and report on the works there. Mr. O'Meara continued to take a lively interest in Durban Harbour, to the engineering literature of which he made many contributions from time to time.

Subsequently he went to America and was occupied in connection with the surveys and construction of the Denver and Rio Grande Railway in Colorado, and later upon important irrigation works in the same State, a Paper descriptive of which he presented to the Institution in 1883[2] and for which he was awarded a Telford Premium. On returning from the United States he was employed by Messrs. Tancred and Arrol, on the construction of the foundations of the Forth Bridge. In September, 1883, he went to Brazil as Chief Resident Engineer of the Brazil Great Southern Railway, on the completion of which he undertook the duties of general manager as well as engineer.

In 1889, he was appointed by Messrs. Punchard McTaggart and

[1] *Post*, p. 385. [2] Minutes of Proceedings Inst. C.E., vol. lxxiii. p. 178.

Company to take charge of the construction of the Ceará Harbour Works in the North of Brazil. He resigned that post in 1893 and, after a stay in England, again proceeded to South Africa, where he was engaged in Pondoland on railway survey work of a difficult character. Later he joined the staff of the Natal-Zululand Railway. On the completion of the work entrusted to him there, Mr. O'Meara was offered and accepted an appointment on the Government Railways of the Orange Free State, and in April, 1897, he was given charge of the construction of the Harrismith-Bethlehem Railway. He died in Harrismith on the 1st April, 1898, after a brief illness.

Mr. O'Meara was an able engineer, a good mathematician, and had a large and varied experience. He was a man of sterling qualities, most honourable and straightforward in all his dealings, and indefatigable and conscientious in the discharge of his duties. He was genial and kindhearted, and always ready to help those in trouble, as well as to give encouragement to young men commencing their career. He was a universal favourite and was much respected by all who knew him.

Mr. O'Meara was elected a Member on the 2nd April, 1878.

THOMAS FRANCIS O'MEARA was born at Nenagh, co. Tipperary, in the year 1837, and was educated at Carlow and Clongows Wood Colleges. At the age of 18 he went to Australia to seek his fortune in the newly discovered goldfields, but after a few years he turned his attention to engineering, and joined the staff of Messrs. Brassey,[1] Wythes,[2] and Longridge,[3] the contractors for the construction of the Mauritius Railways, in 1863 as a sub-agent. After remaining there 2 years, he went in 1865 to India, where he was appointed to a sub-agency by Messrs. Brassey, Wythes and Henfrey, the contractors for the Delhi and Punjab Railway, and was stationed for some time at Julandur. He was next engaged in assisting his brother, Mr. Patrick O'Meara,[4] who was a district agent on Messrs. Brassey, Wythes and Perry's contract for the Chord Line of the East Indian Railway, on which some heavy works were successfully carried out in a limited period.

[1] Minutes of Proceedings Inst. C.E., vol. xxxiii. p. 246.
[2] *Ibid*, vol. xli. p. 232.
[3] *Ibid*, vol. cxxvii. p. 372.
[4] *Ante*, p. 384.

In 1871 he was appointed Assistant Engineer on the Company's staff of the Oudh and Rohilkund Railway, and was placed under the late Mr. P. H. Macadam,[1] then Resident Engineer of the Barribunkie district, near Lucknow. He was soon afterwards promoted to Resident Engineer of the Fyzabad district, and carried out many works of importance under the departmental and small contract systems without the aid of a large contractor. Mr. O'Meara continued to hold various important posts with the Oudh and Rohilkund Company until September, 1886, when, owing to large reductions in the staff, he left the Company's service and took up some small contract work in Central India. Early in 1889 he finally left India, having had a large and varied railway experience of twenty-four years in that empire.

After a period of rest in the old country Mr. O'Meara entered into a three years' agreement in September, 1889, with the Crown Agents for the Colonies as a District Engineer on the Natal Government Railway extensions. In that colony he performed excellent service in prosecuting works of exceptional magnitude on the branch line from Ladysmith to Van Reenen's Pass on the Drakensberg Mountains and thence to Harrismith in the Orange Free State. On the completion of this work he returned to Ireland.

In August, 1896, he again went out to South Africa and joined the staff of Messrs. Stopford and Co., contractors for the construction of the Natal-Zululand Railway, but he unfortunately developed cancer of the tongue, and, after a gallant though hopeless struggle against the disease, at the end of ten months was obliged to return to Ireland, where he died on the 9th September, 1897.

Mr. T. F. O'Meara, or, as he was familiarly called, "Tom O'Meara," was a man of considerable physical strength, hardy constitution, and unwearying energy, a conscientious and zealous worker, of a genial and obliging disposition, and a general favourite. Possessed of an excellent tenor voice, his rendering of Irish songs in particular enlivened many a social gathering, where his presence was always welcome. Mr. O'Meara was married in 1883, and leaves a widow and two children. He was elected an Associate on the 7th December, 1875, and was transferred to the class of Members on the 6th May, 1890.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 437.

JAMES PLATT, a son of Mr. John Platt of Manchester, an engineer well known in the North, was born at Manchester on the 4th February, 1834. In 1847 he entered the drawing office of Messrs. Francis Berry and Sons, Sowerby Bridge, for whom his father was manager. He served his time in the shops and was made foreman at the age of twenty. In 1859 he went to Gloucester to act as manager for Messrs. Savory and Son, for whom he designed some of the first agricultural engines, in which the winding drums encircled the boiler shell. He left them, in 1862, to start a consulting practice, and during the next four years was engaged in designing machinery for, and in equipping, a number of mills in the district. He also designed and superintended the erection, in the Forest of Dean, of the first iron-cased blast furnaces which utilized the waste gases.

In 1866 Mr. Platt entered into partnership with Mr. Samuel Fielding, and founded the now well-known firm of Fielding and Platt, Atlas Works, Gloucester. In 1871 the firm took up, at the request of Mr. R. H. Tweddell,[1] the sole manufacture of that gentleman's hydraulic riveting machines, and two years later made the first portable hydraulic riveting plant, for the Primrose Street Bridge over the Great Eastern Railway at Bishopsgate Street Station, which proved a great success. Mr. Platt was intimately associated with Mr. Tweddell in the development of his system of hydraulic machine tools, which is now well known in all parts of the world.[2]

In 1874, on the death of Mr. Fielding, who was succeeded by his two sons, Mr. Platt became senior partner in the firm. He visited the United States in 1883, and while there read a Paper on "Hydraulic Machine Tools"; he was also in the States with the Iron and Steel Institute, in 1890. While engaged in completing some wire ropeway work in Spain, during the Carlist rebellion, he narrowly escaped being shot. He could only get away in a small steamer, which was under fire while running down the river, the funnel being riddled with bullets.

In 1895 the firm of Fielding and Platt was converted into a private Limited Company, of which Mr. Platt was Chairman of Directors. After the death of Mr. R. H. Tweddell, the Company took over all rights connected with his system of hydraulic machine tools, the patents for which were taken out jointly

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 437.
[2] *Ibid*, vol. lxxiii. p. 64, and vol. cxvii. p. 1.

with Mr. Platt and Mr. John Fielding. Mr. Platt paid a third visit to the United States in 1894, and while there an internal complication began to develop itself, which ultimately caused his death, at his residence at Gloucester, on the 29th December, 1897.

Mr. Platt became a Member of the Institution of Mechanical Engineers in 1871 and a Member of the Council in 1893. He was also a Member of the Iron and Steel Institute and of the Society of Arts. He took great interest in municipal affairs and became Councillor, Alderman, Justice of the Peace and Mayor of Gloucester. He was Deputy-Chairman of the Gloucester Wagon Company, a Director of the Gas Company, a Governor of the Gloucester Infirmary and a Charity Trustee. He was the first President of the Gloucestershire Engineering Society and was a President of the Chamber of Commerce.

Mr. Platt was elected a Member on the 1st December, 1885.

WILLIAM SPOONER TILL was born at Birmingham in 1830, and was educated at King Edward's Grammar School in that city. In 1846, at the age of sixteen, he was articled to Mr. John Piggott Smith,[1] who was at that time Surveyor to the Commissioners under the Birmingham Street Acts. In 1851 the Town Council was formed, Mr. Piggott Smith being appointed the first Borough Surveyor, which office he held until 1857, when he was succeeded by Mr. Till, who had been Assistant Surveyor under him.

It is stated that when Mr. Till took charge of the Surveyor's Department in 1857 the centre of the town was little better than a network of narrow streets, while some of the roads in the borough were studded with ruts and holes, one street being so bad in this respect that some of the holes had to be fenced round and lighted after dusk to prevent accidents. Under the municipal government this state of things was entirely altered. Numerous works of street improvements and sewering were undertaken, and from the time of his appointment as Borough Surveyor until his retirement from the active duties of that office to the post of Consulting Surveyor in 1896, Mr. Till was busily employed, his department

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[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 594.

increasing until his position became that of the head of a large staff. During his surveyorship many street improvements were carried out, particularly in the centre of the city, which was practically re-modelled, chiefly owing to the formation of Corporation Street and to the extensions of the railway stations belonging to the London and North-Western and Midland Companies, whilst other public works carried out comprise the erection of the fish and vegetable markets, interception works, the inverting and deepening of the River Rea and Hockley Brook, the construction of about 14 miles of double and 6 miles of single line of tramway, and the laying out of the City Cemetery at Witton (about 100 acres in extent) and of various parks and recreation grounds.

In 1877 the Birmingham Tame and Rea Drainage District was formed, comprising the Borough of Birmingham, the Local Government districts of Aston Manor, Handsworth, Smethwick, Balsall Heath, Harborne and Saltley, and portions of the rural sanitary districts of Aston, King's Norton, and West Bromwich, enlarged in 1881 by the addition of the parish (now borough) of Sutton Coldfield. Mr. Till was appointed Engineer to the Joint Board, his principal duties being the promotion of facilities for joint intercepting works, and the purification of the sewage, the dry weather flow of which is now about 22 million gallons per day.

In 1881 Mr. Till prepared a scheme for the acquisition and laying out of about 1,000 acres of land, for an irrigation farm, in addition to the system of purification by lime in tanks then in operation; and subsequently negotiated the purchases and carried out the extensive works necessary for putting the scheme into execution. In 1896 he recommended the extension of the farm to practically double its then area, and an Act was obtained empowering the Board to purchase the land and carry out the works.

Mr. Till died at his residence in Holyhead Road, Handsworth, on the 22nd of February, 1898. A most efficient municipal officer, he not only enjoyed the confidence of the City Council and Drainage Board, but his reputation for sound judgment and fairness was such that his advice was frequently sought in disputes and questions of difficulty arising in connection with the suburban sanitary authorities. In the discharge of his duties he not only proved himself an able engineer, but also an excellent man of business. He was courteous and kindly in manner and a

firm friend, being much esteemed not only in private life, but also by the large staff over which he presided, and by the many professional and public men with whom his official position brought him into contact.

Mr. Till was elected a Member on the 2nd February, 1875.

JOHN SUTHERLAND VALENTINE [1] was born at Hartshorne, near Burton-upon-Trent, in Derbyshire, on the 21st September, 1813. He was educated at the Grammar School at Coleshill, Warwickshire, where his father then resided, engaged as Surveyor of several of the turnpike roads in the district, upon which he designed and carried out many important improvements.

At the age of sixteen young Valentine entered the office of Mr. John Dumolo, a land and mineral surveyor living at Kingsbury, near Tamworth, where he remained five or six years, during which period he was employed on the preliminary surveys of the Birmingham and Liverpool, and the London and Birmingham Railways. In the year 1835 he entered the office of the late Mr. John Urpeth Rastrick,[2] under whom he was employed for a period of ten years upon most of the railways projected by that engineer. In the year 1845 Mr. Valentine was appointed joint engineer with Mr. Rastrick of the proposed railway from Ambergate by Nottingham and Grantham to Boston and Spalding, the preliminary surveys for which he superintended; but he resigned this appointment in favour of Mr. John Underwood, afterwards Engineer-in-chief to the Midland Railway Company (under whose superintendence the line from Nottingham to Grantham was constructed), having been appointed engineer to construct the railways from Lynn to Ely, Lynn to Wisbech, and Lynn to East Dereham, in Norfolk, which had been laid out and the Acts obtained under his charge as Assistant Engineer under Mr. Rastrick. The whole of the works upon these lines were designed and executed under Mr. Valentine's direction. In the following year, upon the resignation of the late Mr. G. W. Buck [3] through ill-health, he succeeded that gentleman

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[1] This memoir is a reprint, with slight modifications and additions, of MS. notes made by Mr. Valentine himself.

[2] Minutes of Proceedings Inst. C.E., vol. xvi. p. 128.

[3] *Ibid*, vol. xiv. p. 128.

as engineer of the Ely and Huntingdon Railway, and constructed the portion of that line from St. Ives to Huntingdon.

After the completion of these railways, which had been amalgamated under the title of the "East Anglian Railways Company," and now form part of the Great Eastern Railway system, Mr. Valentine removed to London and was actively engaged there in engineering matters until 1853, when he was appointed Engineer to the line then projected under the title of the "Central Peninsular Railway of Portugal" from Lisbon to Oporto and the frontier of Spain. In the autumn of that year he went to reside at Lisbon, and laid out and superintended the construction of the first section of that line from Lisbon to Santarem, which was the first railway made in Portugal. In the year 1859 Mr. Valentine projected the "South-Eastern of Portugal Railway" from Vendas Novas to Evora and Beja in the province of the "Alemtejo," a concession for which he obtained from the Portuguese Government for a company formed in London. This line was laid out and the contract let to Mr. Edward Price under his superintendence, soon after which he resigned his connection with it. The following railways have since that time been designed and executed under Mr. Valentine's superintendence; (1861–62) the line from King's Lynn to Hunstanton, the West Norfolk Railway from Heacham to Wells, the Ely, Haddenham, and Sutton Railway in Cambridgeshire, and the Thetford and Watton Railway; (1873–75) the Watton and Swaffham Railway; (1876–7) the Sutton and St. Ives Railway in Cambridgeshire and Huntingdonshire, and the laying out and obtaining the Act for the Lynn and Fakenham Railway in Norfolk, which has since been constructed by Messrs. Wilkinson and Jarvis and extended to Norwich and Yarmouth.

In the year 1862, upon the bursting of the sluice on the Middle Level Drainage and immediately afterwards of the sluice on the Smeeth and Fen drainage in Marshland, Mr. Valentine was retained by the Commissioners of Sewers for the county of Norfolk to advise them as to the best mode of securing the district of Marshland from inundation, the sluice upon the "Marshland drain" being the only one remaining to prevent the whole of that fertile country being submerged. To effect this object he built a timber dam or sluice across the drain above the main sluice on the River Ouse, and connected it with the banks of that river by banks on each side of the drains of sufficient height to keep out the tide, and by this means secured the country against any further catastrophe. About the same period Mr. Valentine also

constructed defensive works for the protection of the low lands extending along the sea coast from Snettisham Beach by Hunstanton to Holme on the estate of Mr. Le Strange, the sea having in several places breached the barrier of sand and shingle which extends along a great portion of this part of the property.

In 1871 he constructed works for supplying the new town of Hunstanton St. Edmunds with water. In the year 1876 he was appointed Engineer to the King's Lynn Dock Company, the large corn warehouses for which were designed and built under his superintendence, and in 1877 he laid out and carried through Parliament the extension dock which was constructed (1881–83) under his direction. He became Chairman of the Hunstanton and West Norfolk Railway Company, the Ely and St. Ives Railway Company, and the Hunstanton Water Company. He was elected a Director of the King's Lynn Docks and Railway Company in 1888, and on the death of Sir Lewis W. Jarvis at the latter end of that year he became Chairman of the Company. He was also a Director of Moule's Earth Closet Company. From the year 1875 to the completion of the Bentinck Dock at King's Lynn in 1884, his son, Mr. Frederick Valentine, was in partnership with him.

About the year 1885 Mr. Valentine retired from business, though not from work, for his active duties in connection with the public companies with which he was associated were maintained almost to the last. He was for many years a well-known figure in the committee-rooms of both Houses of Parliament. His long connection with the railway world and the experience he obtained when promoting his early schemes rendered him a good and valuable witness, and he was retained in many of the great railway fights. After a residence at Kensington of nearly forty years he, in 1893, removed to Hythe, in Kent, where he died on the 24th March, 1898, in his eighty-fifth year.

Mr. Valentine was elected a Member on the 2nd May, 1848. He contributed the following Papers to the Minutes of Proceedings: "Description of a timber bridge erected over the river at Hilgay on the line of the Lynn and Ely Railway,"[1] and "Description of the line and works of the railway from Lisbon to Santarem."[2]

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[1] Minutes of Proceedings Inst. C.E., vol. ix. p. 149.
[2] *Ibid*, vol. xviii. p. 1.

JOHN WHITTON was born at Foulby, near Wakefield, Yorkshire, in 1819. In 1835 he was articled to Mr. William Billington, who designed and carried out the Wakefield Waterworks and other engineering undertakings. In the early days of railway enterprise he was busily engaged for several years assisting Mr. Billington in taking surveys and levels and in the preparation of Parliamentary plans, in connection not only with some important railway schemes but also with a proposed ship canal from Liverpool to Manchester, which he designed and of the surveys for which he had sole charge. About the year 1846 he was engaged under Sir John Hawkshaw [1] on Parliamentary surveys and on railway work in Lancashire. In 1848 and 1849 he acted as an Assistant Engineer on the construction of the East Lincolnshire Railways under Mr. (now Sir John) Fowler, and was subsequently engaged under that gentleman in completing the Oxford, Worcester and Wolverhampton Railway, and on railway construction in Yorkshire and elsewhere between 1851 and 1856.

Mr. Whitton's energies were now afforded a wider scope. In March, 1856, on the recommendation of the President of the Board of Trade, he was appointed Engineer-in-Chief of the New South Wales Government Railways. Subsequently he had sole charge of the construction of railways, and also of railway surveys, in that Colony; and for many years he was, in addition, responsible for the locomotive and permanent way departments. The colony was fortunate in having at the early stage of railway construction a man of sound professional training and great rectitude of character, independence and foresight. In no instance did he render greater service than by opposing the agitation for break of gauge at Goulburn and Bathurst. At that time certain critics of railway construction thought it would suffice to stop the trunk lines at those points on the Southern and Western roads and continue construction on the system of light railways. Mr. Whitton withstood those representations and secured for the colony a uniform gauge, a service which probably involved more direct and indirect gain to the community than can now readily be realized. He was a man of the strictest integrity and of great firmness, and he successfully resisted political pressure, insisting on controlling the lines in what he deemed the best way, even though his opinion clashed with that of the Government of the day. On his arrival in Sydney in 1856 there were only 22 miles of

[1] Minutes of Proceedings Inst. C.E., vol. cvi. p. 321.

railways in existence in New South Wales. On his retirement in 1890 he left over 2,000 miles of lines opened for traffic. The mere mileage, however, does not convey an adequate conception of his work, for the construction of the first 500 or 600 miles of the New South Wales Railways, including, as they did, very heavy works on the Great Western line over the Blue Mountains and on the first portions of the Great Southern line, took many years to effect and cost as much as £70,000 to £80,000 per mile, of single line track.

Mr. Whitton died at Mittagong, near Sydney, on the 20th of February, 1898, at the age of 79. His connection with the Institution was one of nearly 44 years' standing, he having been elected a Member on the 2nd of May, 1854.

EDWARD BREWSTER, born at Castlebar, co. Mayo, on the 30th September, 1860, was the only son of the late Mr. Henry Brewster, who for thirty-six years was County Surveyor in Mayo. He was educated at Dr. Chambers's School, Kingstown, and afterwards at Trinity College, Dublin, where, in December, 1883, he obtained the degree of Bachelor of Arts and Engineering. During 1884 and 1885 he gained, under his brother-in-law, Mr. Edward Glover, large and varied experience on sea-coast defence works, including fishery piers and the preparation of designs for the viaduct connecting Achill Island with the mainland. In 1886, under Mr. P. C. Cowan, he acted as Resident Engineer on the Achill Sound Viaduct, and afterwards on the extension of the Ship Quay at Westport Harbour. In 1887 he was employed under Mr. A. E. Joyce on surveys and contract plans for the Claremorris and Ballinrobe Railway, and the Loughrea and Attymon Railway. Since 1888 he practised in Castlebar, and from 1890 acted as Engineer to the Board of Guardians of the district.

Mr. Brewster died on the 27th May, 1897. He was extremely conscientious and accurate, and he had an excellent knowledge of materials and workmanship. His gentlemanly and kindly disposition made him popular with all who were brought in professional contact with him, from the humblest workman to the contractor and employer. In private life he was loved for his sterling qualities, which gained him many friends. He was elected an Associate Member on the 1st May, 1894.

FREDERICK WILLIAM HUDSON was born at Hull on the 22nd March, 1859, and was articled in 1878 to Messrs. Oldham[1] and Bohn, of that city, under whom he was engaged on the sewerage of Great Driffield and other works. He was then for five years an Assistant Engineer on the Hull and Barnsley Railway. In November, 1887, he was appointed to the contractors' staff of the Manchester Ship Canal, and was engaged on the Warrington section for three years. In 1890 he went to Bristol as Chief Assistant to the Docks Engineer, Mr. J. M. McCurrich, which post he occupied until September, 1897, when illness forced him to give up work. During that period he assisted in carrying out new wharves and warehouses at Bristol, the floating dock and warehouses at Avonmouth, and the works in connection with the improvement of the River Avon.

Mr. Hudson died at his residence at Clifton on the 15th March, 1898. The formation of the Bristol Association of Engineers was in a large measure due to his exertions; he acted as Honorary Secretary from its commencement, and almost up to the close of his life took an active interest in its welfare. Mr. Hudson was elected an Associate Member on the 2nd December, 1890.

THOMAS INMAN was born on the 29th February, 1848, at Ruecroft, near Sedbergh, Yorkshire, and died on the 3rd February, 1898, at Madras. He was educated at the Sedbergh Grammar School and subsequently at Chudleigh Grammar School under his cousin, the Rev. J. W. Inman, M.A. After serving a pupilage to Mr. J. W. Wilson, he was employed for two years as Resident Engineer on the construction of the Madras tramways. In 1875 he was appointed an Assistant Engineer in the service of the Mysore Government, and was posted to the Chemoga District. In 1879 he was transferred to the Public Works Department, and was for many years Executive Engineer of the Bangalore Division and of the French Rocks Division. Mr. Inman married, in August 1870, Miss Sophia Ware, daughter of the late Mr. Thomas Ware, of the Manor House, Hackney, and Teversham, Cambridgeshire, solicitor, by whom he had one son. He was elected an Associate Member on the 7th December, 1886.

[1] Minutes of Proceedings Inst. C.E., vol. ciii. p. 377.

WILLIAM EDWARD NEWHAM, born in January, 1857, in the parish of Barrow-on-Soar, Leicestershire, of which his father was then Vicar, was educated at Uppingham School. In 1874 he entered the Royal Indian Engineering College, Coopers Hill, and after three years' study obtained an appointment as Assistant Engineer in the Indian Public Works Department on the 1st October, 1877. On arriving in India he was employed on the Rajputana-Malwa State Railway, on the Bhopal State Railway, and on the Sagor surveys. In November, 1881, he was posted to the Bengal-Nagpur Railway surveys, on which he was engaged until November, 1883, and did excellent work. In 1884 he was transferred to the Northern Bengal State Railway, and was employed there for a year on open line and on the construction of the eastern branches. In November, 1885, he took furlough and visited Australia and New Zealand. On his return from furlough in November, 1886, he was posted to Burma and employed on the Tounghoo Mandalay Railway, and afterwards on the Mu Valley Railway, of which for a time he acted as Engineer-in-Chief. His services on the Tounghoo Mandalay Railway were acknowledged by the Government of India.

In February, 1894, Mr. Newham retired from the Indian Government service, under the special retirement rules of 1893, and went to California. He bought a fruit farm in San Diego country, intending to settle there. When, however, the Southern Punjab Railway was commenced in 1895, he was offered the appointment of Deputy Chief Engineer, which he accepted, and returning to India in September of that year he did excellent work for that company until the time of his death. When the construction of the Southern Punjab line was nearly completed, Mr. Newham was offered the more permanent appointment of Deputy Chief Engineer of the Burma Railways, and was preparing to join that appointment when he was taken ill. Though his illness was not at first thought to be serious, yet it ultimately proved to be enteric fever, from which he died at Kasauli, Punjab, on the 2nd May, 1897.

The record of his work at school, as inscribed on the medal awarded to him at Uppingham "for good work and unblemished character," was fully borne out by Mr. Newham's subsequent career. Everything he did was done thoroughly and carefully, and his character was not only an unblemished but a most loveable one. He was a good friend and a good worker, and,

above all, a good son and brother, helping, as he did, in many ways his younger brothers and sisters. Mr. Newham was elected an Associate Member on the 5th December, 1882.

EDWARD JAMES PURNELL, Jun., eldest son of the Water Engineer of Coventry, died at his residence, Queen Victoria Road, Coventry, on the 27th February, 1898. He was born on the 2nd April, 1856, and, after serving articles to his father, was in business for several years as an architect and surveyor, and in both capacities had a good practice. He was Surveyor to the Kenilworth Local Board and to its successor, the Urban District Council, and was also Secretary to the Water Company of that town. These positions were, however, relinquished before his death. He also designed and carried out several large works for cycle makers in Coventry.

Mr. Purnell was elected an Associate Member on the 3rd March, 1885.

EDMUND ROTHWELL, born at Darwen on the 28th October, 1858, began his engineering career as a pupil to the late Mr. John Cunliffe, Surveyor to the Darwen Local Board. After remaining with that gentleman for some years as an assistant, he was appointed, in 1883, Surveyor to the Local Board of Norden, near Rochdale. In May, 1887, he became Secretary, and in the following November Manager and Secretary to the Bury, Rochdale and Oldham Steam Tramway Company, which posts he held until his death. During that period he carried out works of permanent-way reconstruction, costing £25,000. Mr. Rothwell died at Southport on the 6th February, 1898. He was elected an Associate Member on the 7th March, 1893.

WILLIAM HARRY SCRIVEN, born on the 25th March, 1850, at Chippenham, Wilts, obtained his first professional experience in the District Engineer's office of the Great Western Railway, at Leamington, where he remained from 1867 until 1872. He was then

for eighteen months in the Divisional Engineer's office of the same Company at Oxford, and was engaged in superintending various new works, among them being the widening of a portion of the Bristol and South Wales Union Railway, and the construction of a junction with the Clifton Extension line. From 1874 to 1878 he was in charge for the Great Western Company of the construction of goods sheds and approaches at Bristol, Bath and Corsham. In 1878 Mr. Scriven entered the service of the East Indian Railway Company, in which he remained for twenty years. Early in the present year failing health obliged him to return to England. He died at 44 Cambridge Gardens, Hastings, on the 28th March, 1898. Mr. Scriven was elected an Associate on the 1st February, 1876, and was subsequently placed in the class of Associate Members.

EDWARD DUNCAN STONEY, only son of the late Francis Goold Morony Stoney,[1] was born on the 31st July, 1868. After a three years' course at the City and Guilds of London Central Institution, under Professor Unwin, he obtained the diploma of Associate of the Institute in 1889. In July of the same year he entered the service of Messrs. Ransomes and Rapier, of Ipswich, and took charge of the ironwork for the Weaver Sluices on the Manchester Ship-Canal. In the following year he was entrusted with the charge of all sluice erection work on that Canal. This work was intermittent and necessitated frequent visits to the shops at Ipswich and an intimate knowledge of the manufacture as carried on therein. A method of calculating the position and loading of beams in sluices was devised by Mr. Stoney and was adopted by Messrs. Ransomes and Rapier.

In 1892 Mr. Stoney was appointed by Messrs. Ransomes and Rapier Resident Engineer in charge of the steel bridge and the sluices on the Thames at Richmond, on which he was engaged for two years. He was then chiefly at Ipswich, but still supervised all erection work. In the autumn of 1894 the first prize of 100 guineas was awarded to him for plans and estimates for a ship-canal for the improvement of the River Parrett from the sea to the town of Bridgwater.[2] In the following year he was

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[1] Minutes of Proceedings Inst. C.E., vol. cxxx. p. 316.
[2] *The Engineer*, vol. lxxx. p. 438.

employed on the design of the sluices and bridge for the River Clyde at Glasgow, and latterly he was responsible for all sluice designs emanating from Messrs. Ransomes and Rapier. The strain of the past year unfortunately proved too great, and on the 8th February, 1898, he succumbed to an attack of pleurisy and pneumonia. His early death, following so soon on that of his father, is greatly regretted, for he gave promise of a useful and successful career.

Mr. Stoney was elected an Associate Member on the 4th December, 1894.

GEORGE JAMES MUNDAY, who died on the 20th September, 1897, at his residence at Snaresbrook, Essex, was born at Rotherhithe on the 9th November, 1820. He was the second son of Mr. Thomas Munday, who at that time was acting as an agent for his brother, Mr. George F. Munday, contractor, of Old Ford, London. The subject of this notice, after being educated at a private school, was articled in 1836 to an accountant in London. Completing his articles in 1841 he entered the service of a firm of land surveyors and estate agents. Some time in 1842 he left this service in order to take up on his own account railway survey work for parliamentary purposes, chiefly in North Wales.

Mr. Munday had been in the habit of giving occasional assistance in his uncle's business, and was thus familiar with a contractor's duties from an early age. Meanwhile Mr. George F. Munday had died and had been succeeded in the business by his brother, Mr. James W. Munday, who in the year 1843 was carrying out some large contracts for the drainage of the city of Hamburg. At his uncle's invitation George Munday joined him in partnership there, and proceeding to Hamburg he assisted in the superintendence of the work. From the date of his return to London down to the year 1887, when failing health compelled him to forego active exertion, he was employed in carrying out numerous works; from 1843 to 1852 in partnership with his uncle, as James and George Munday; from 1852 to 1881 alone, as George Munday; and since 1881 in partnership with his sons, as George Munday and Sons. Among these works may be mentioned large drainage operations in the Fens under Mr. James Walker;[1]

[1] Minutes of Proceedings Inst. C.E., vol. xxii. p. 630.

the Wicksteed engine-house at Old Ford for the East London Water Company; the reconstruction of Teddington, Molesey and Shepperton weirs, and Bray Lock, for the Thames Conservancy; dry docks at Blackwall Yard, for Messrs. Wigram & Co.; extensive works on the River Kennet, at Reading, under Mr. James Mansergh; sewerage work in the West Ham marshes, under Sir Robert Rawlinson; the construction of the new pumping-station at Abbey Mills for the London County Council, under Sir Alexander Binnie; and a great number of Government works under the Royal Engineers.

Mr. Munday was selected in 1848, by Mr. James Walker, to act with him in a complete examination of, and report upon, the sewers of the City of London. In 1851, having, in conjunction with his uncle, rendered some services to Her Majesty's Commissioners for the Great Exhibition, he was awarded a bronze medal and a certificate "for services." In 1854, after carrying out some difficult work at Richmond, he read a Paper at the Institution on "Coffer Dams,"[1] and was awarded a Premium. In 1860 he was appointed Engineer to the Court of Sewers at Wisbech, and had charge of the work done to the river banks under their authority. He held this appointment many years. Latterly Mr. Munday ceased to attend to business, though remaining a partner in the firm, and passed the end of his days in literary study and research, which had always been his hobby. He was a man of considerable learning, his classical and linguistic attainments being unusual for one so actively engaged in other pursuits.

He was elected an Associate on the 2nd April, 1850.

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[1] Minutes of Proceedings, vol. xiv. p. 32.

*** The following deaths have also been made known since the 26th February, 1898:—

Honorary Members.

BESSEMER, *Sir* HENRY; *died* 15 March, 1898.

SCHNEIDER, HENRI; *died* 18 May, 1898.

Members.

DYER, HENRY CLEMENT SWINNERTON, *Col.* R.A. *ret.*; *died* 21 March, 1898.

GALE, HENRY; *died* 3 March, 1898.

GREENWOOD, GEORGE; *died* 16 April, 1898.

HAYTER, HARRISON, *Past-President*; *died* 5 May, 1898.

METHVEN, JOHN; *died* 4 April, 1898.

MUDD, THOMAS; *died* 17 May, 1898.

PRICE, EDWARD BELLINGHAM, B.A. (*Dubl.*); *died* 13 January, 1898.

RAWLINSON, *Sir* ROBERT, K.C.B., *Past-President*; *died* 31 May, 1898.

RENDEL, WILLIAM STUART; *died* 4 May, 1898.

SCHRAM, JOHN RICHARD; *died* 20 April, 1898.

STENT, SYDNEY; *died* 20 May, 1898.

STRYPE, WILLIAM GEORGE; *died* 14 March, 1898.

TATAM, EDWARD JOHN.

WESTWOOD, JOSEPH; *died* 18 April, 1898.

Associates.

LINDSELL, JOHN BARBER, *Lt.-Col.* R.E. *ret.*; *died* 6 May, 1898.

RAWLINS, JOHN; *died* 22 May, 1898.

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 31 May, 1898.

Sect. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

Magnetic Declination in the United States. H. Gannett.

(United States Geological Survey. Seventeenth Annual Report, p. 201.)

In a Paper covering 240 pages the Author has collected all the data available regarding magnetic declination in the United States, with a view to meet the needs of those who have occasion to use the magnetic needle in surveying or have to deal with surveys that have been run with the needle in past times. The results are presented in the form of Tables, showing the approximate reduction to the year 1900, the declination being given in the Tables by counties, cities, and towns. A map showing the mean results for the year 1900 accompanies the Paper. The regions in which the data are the most conflicting are those in which local attraction is great, as in northern Michigan and Wisconsin, and in the south-eastern States, where the data are scanty.

B. H. B.

The Haskin Process of Preserving Timber.

(The Engineer, 28 January, 1898, p. 81.)

The process consists in subjecting the timber to be preserved to air at a temperature of 400° F., and a pressure of 200 lbs. per square inch. The resolution of the woody fibre and sap *in situ*, at this temperature, results in the production of such substances as wood creosote, which preserve the timber without deteriorating any of its properties. The vessels, in which the result is effected, are cylinders, 120 feet long and 6 feet 6 inches in diameter, into which the timber is run on tram lines. After drying any moisture off the timber with steam, the vessels are closed by a door, and heated compressed air is driven in and kept in circulation.

A. W. B.

Cement Testing during the Year 1896-7. MAX GARY.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1897, p. 209.)

The publication of the cement testing during the above year is given in the same form as for previous years.[1]

Up to the year 1890 the attention of Portland-cement makers was directed principally to raising the strength of the cement, but in that year attention was directed to the fact that increased strength did not always mean an improvement in the other necessary qualities.

Special attention has been given lately to the properties of cement as regards constancy of volume and the accelerated tests in connection therewith.

Three methods of testing are used:—

1. The "drying" test, in which 100 grams of cement are mixed with water, then placed on a sheet of moist blotting-paper lying on a flat glass or metal plate so as to form a thin cake. After setting, the cake is kept in a moist atmosphere for 24 hours and then heated by means of a water bath to about 100° C., until all water-vapour is driven off.

2. The "glow" test, in which 300 grams of cement are mixed with water, and rapidly formed in the hand to the shape of a ball. It is then placed on a plate of plaster of Paris, over a thin iron plate and heated with the flame of a Bunsen burner, until all the water is driven off.

3. The "boiling" test, in which 100 grams of cement are made into a thin cake, placed in a moist atmosphere for 24 hours, then immersed in water, which is gradually raised to boiling-point aud kept boiling for 3 hours.

About 40 per cent. of the specimens examined were damaged by the drying test, 34 per cent. by the glow test, and 37 per cent. by the boiling test; 8 per cent. of the specimens failed under drying only, 11 per cent. failed under the glow test only, and 1 per cent. under the boiling test only; 2 per cent. failed under the drying and the glow tests, 7 per cent. under the glow and the boiling tests, and 18 per cent. under the drying and the boiling tests; 12 per cent. failed under all three tests.

Comparing these tests with the tests of compressive and tensile strengths, it is concluded that a cement may fail under one or other of them, and yet prove a reliable cement in ordinary practice, so that no definite conclusion may be drawn from them.

Enquiries were made as to the behaviour in practice of ten cements which, as the result of these tests, were looked upon as suspicious, but up to the present not one has proved unreliable.

A. S.

[1] Minutes of Proceedings Inst. C.E., vol. cxxix. p. 405.

New Portland-Cement Factory at Civita Vecchia.

(L'Industria, 20 February, 1898, p. 114.)

The hills to the north-east of Civita Vecchia are composed largely of a stone containing about 40 per cent. of calcium oxide, 15 per cent. of the oxides of iron and aluminium, and 18 per cent. of silica and silicates insoluble in hydrochloric acid. The constitution of this mineral, and, in especial, the fact that it contains no magnesium, renders it well adapted for the manufacture of Portland cement. The plant recently erected for this purpose is near the railway and covers an area of about 28,000 square metres. The stone is brought from open quarries at a distance of from 2 to 5 kilometres.

At present two furnaces are in action, but three others are in course of construction, and the ground is laid out for four more. The furnaces, which are on the Aalborg system, are of brick lined with refractory material, and hooped externally with iron. They are 30 metres high and from 2 to 3 metres internal diameter. They are fed with material and fuel by suitable apertures near the top, and the calcined stone passes through the iron grate which forms the bottom of the furnace, the action being continuous. The charge is about 30 tons per day, and the yield is about 60 per cent., the fuel required being about 90 kilograms per ton. The calcined material is picked over to remove any that may be imperfectly burnt, slightly moistened with water, and allowed to remain in heaps for 2 months or 3 months. It is then passed through a revolving drum containing a large number of heavy steel balls, by the action of which it is coarsely powdered. These machines are by Fried. Krupp Grusonwerk, of Magdeburg-Buckau.

The final grinding is effected in tube-mills on the Davidson system, each mill consisting of a cylinder, 1·25 metre in diameter and 6 metres long, containing some 3,600 kilograms of flint pebbles, and making 27 revolutions per minute. The yield of the tube mills is about 25 quintals per hour.

Power is supplied by gas-engines made by Langen and Wolff, of Milan. The gas, which is made by two generators of the Dowson type, contains about 70 per cent. carbonic oxide and 15 per cent. hydrogen. The engines are of 75 HP., and consume 550 grams of anthracite per HP.-hour.

G. J. B.

Experiments with Monier Slabs. R. P. T. Tutein Nolthenius.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1895–96, p. 4.)

During the construction of a culvert at Heusden, built on Monier's system, a number of experiments were conducted by the Author on the material, which consists of iron rods em-

bedded in concrete. In investigating this combination it was found that, although the price is higher than for concrete only, the strength is so much greater that it becomes economical where lightness of construction is desirable. The average price of a cubic metre of concrete of 1 to 3 being 20*s.*, the cost per cubic metre of the combined material comes to 70*s.* to 80*s.* per cubic metre, according to the diameter and number of the iron rods employed. The strength was found to be about equal to that of pine beams of the same dimensions, where iron and concrete were combined in a manner to throw the tensile strains principally on the iron rods and compression on the concrete. It may therefore be valuable where dampness and other causes render the use of timber undesirable. The Paper is accompanied by numerous Tables of experiments and drawings.

H. S.

Monier Beams and their Application to Foundations in Soft Soils. R. P. T. Tutein Nolthenius.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1896–97, p. 103.)

The Author's experience of Monier material [1] led him to investigate the question whether this combination of iron rods and Portland cement concrete could with advantage be used in other ways than had as yet been thought of. Former experiments showed that the strength of the material, if judiciously combined, could be safely taken as that of timber of the same dimensions. In the case under consideration, a building had to be placed on a new-made bank, where a pile foundation was impracticable. The specification therefore prescribed that the lower footings of the foundation for the walls were to be laid on rafts of heavy beams bolted together. Instead of these intended timber sleepers, beams of concrete and iron rods were substituted, and this proved satisfactory. In this case the greater weight was no objection, deterioration of the material need not be feared, and by employing this mode about 36 per cent. was saved in the cost of the foundation.

H. S.

Experimental Researches on the Shearing and Punching of Metals. C. Frémont.

(Bulletin de la Société de l'Encouragement, 1897, p. 1177.)

In the course of the Paper, which is copiously illustrated by diagrams and photographs, the Author describes his rotation dynamometer and improved elasticitimeter, for recording as a diagram

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[1] *Ante*, p. 404.

the power absorbed by shearing- and punching-machines, and the resistance overcome by the tools at each instant throughout the operation. By the aid of these instruments he finds that speed has no influence on the amount of power required for shearing, the diagrams being practically constant whether the machine is run quick or slow. He also finds, by examining the striations in the interior of iron submitted to the operation of shearing, that the curves produced therein are concentric instead of parallel, and that the effect is one of traction, the fibres being gradually attenuated in curving until the point of rupture is reached. A similar result was observed in the case of punching (on a countersunk bed-plate), the displacement produced being effected by the drawing out of the fibres until their final rupture is completed by the edge of the punching tool. He considers that the resistance offered by the metal to the entrance of the nipple of the punch can be utilized as an indication of the degree of hardness of the former, and may replace the test proposed by Colonel Martel.

Another subject dealt with is the advantage of making the matrix of the punching-machine of a somewhat larger area than that occupied by the face of the punch, since otherwise an effort of compression is exerted laterally on the lower strata of fibres in the metal subjected to the operation, and results in the bending of the rod or sheet and in the production of internal fissures. This compression also gives rise to deterioration of the metal and renders it more brittle, an effect proved by removing in the lathe a thin collar of the metal surrounding the punched hole, which collar proved harder and less ductile under pressure than a similar one removed from the same metal perforated by boring. The detached collarette of metal at the upper part of the punched core varies inversely with the amount of play left between the punch and the matrix, and disappears when this play is equal to about one-fourth the thickness of the metal punched.

After discussing the question of shearing tests as a substitute for breaking-strain tests, the Author concludes by dealing with the best form of punch for producing a perfectly cylindrical aperture without deterioration of the punched metal. For fine work, such as punching boiler-plate, he finds the best effect produced by a punch in the form of a stepped screw, the successive cutting-edges of which gradually widen the upper part of the otherwise conical hole with a minimum of deformation. In the case of ordinary rivet-holes, where an inferior degree of precision is required, a punch with one V-shaped step will produce satisfactory results.

C. S.

Tests of Cast-Iron Columns by the Department of Buildings of New York.

(Engineering News, New York, January, 1898, p. 27.)

The tests were made in December, 1897, with the hydraulic testing machine at the works of the Phœnix Bridge Company.[1] In order to test this machine a segmental steel column was made and its compression under various loads carefully measured at the United States Arsenal at Watertown. These experiments were then repeated with the same column at the works, and it was found that the average amount of friction in the machine was 15·4 per cent. of the pressure indicated by the hydraulic pressure gauge, the amount being 17 per cent. for pressures lower than any breaking strain afterwards recorded. Instead of the actual piston-area of 3,227 square inches only 2,730 square inches were accordingly assumed in the computations. Illustrations are given from which it appears that all columns had flat ends and were tested in a horizontal position and with supports at three or four points in their length. Among six columns 15 feet $10\frac{1}{4}$ inches long and 15 inches outer diameter, one, 1 inch thick, broke with 30,830 lbs., three, about $1\frac{1}{8}$ inch, with 27,700 lbs., 24,900 lbs., and 25,200 lbs., and two, about $1\frac{3}{16}$ inch, with 32,100 lbs., and over 40,400 lbs. per square inch. Two columns 13 feet 4 inches long, 8 inches in diameter and 1 inch thick, broke with 31,900 lbs. and 26,800 lbs., and two, 10 feet long, $6\frac{1}{8}$ inches in diameter and 1 inch thick, broke with 22,700 lbs. and 26,300 lbs. per square inch.

Reference is made to some experiments made for the same department with columns 8 inches to 14 inches in diameter, bearing out the above experiments, and the conclusion is drawn that, while according to recognised formulas the factor of safety would be 5, it is actually in some cases little more than 2.

M. A. E.

Tests of the Strength of Brackets on Cast-Iron Columns.

(Engineering News, New York, January, 1898, p. 36.)

The experiments described in the preceding abstract were extended as follows:—

The brackets cast on to the side of the columns for the support of floor-girders, and consisting of a shelf projecting 4 inches or 5 inches and of one or two vertical ribs underneath, the latter being generally 5 inches to 7 inches and, only in one case, $13\frac{1}{2}$ inches long, were tested. Eleven tests were made with loads distributed on the shelf and eleven with loads on end of shelf. It was generally found that a hole was torn in columns of 15 inches diameter, and that the bracket was broken off from

[1] *Engineering News*, New York, 10 January, 1891.

columns of 6 inches diameter. Assuming that in the former cases the strength of the bracket bears some relation to the following sectional areas, viz., a, of the surface of fracture above bottom of shelf, b, of the shelf at the junction with the column, and c of the shelf and ribs together, and dividing these into the breaking load, the figures thus obtained are, for distributed loads, a = 5,700 to 18,000 lbs., b = 7,100 to 23,700 lbs., c = 6,500 to 10,900 lbs., and, for end loads, a = 3,600 to 8,400 lbs., b = 4,200 to 12,100 lbs., c = 3,600 to 5,600 lbs. In the latter cases where the bracket was broken off from the columns the figures are for distributed loads, c = 4,100 to 10,900 lbs., and, for end loads, c = 2,450 to 5,600 lbs.

It is thought unlikely that such low figures had hitherto been used in the design of brackets, and the opinion is expressed that the results of the tests of columns show the utter worthlessness of the Gordon formula.

M. A .E.

Corrosion of Iron and Steel Plates and Tubes. Prof. FINKENER.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1897, p. 277.)

The chemical composition of twelve specimens of iron, or steel plates, or tubes which had corroded badly is given in this Paper. None of the twelve specimens were poor in manganese and poor in phosphorus. Whether the presence of these elements be the immediate or secondary cause of failure, it seems desirable that when iron or steel is subjected to acidulated water at high temperatures only the smallest possible amounts of manganese and phosphorus should be allowed.

A. S.

Testing Waterproof Fabrics. EDUARD ALSCHER.

(Mittheilungen über Gegenstäude des Artillerie- und Genie-Wesens, 1898, p. 54.)

Following upon an earlier Paper [1] the Author discusses his formula—

$$w = a\,t,$$

where a = the head of water in centimetres, which, being gradually increased, penetrates the fabric under test in the Author's machine;

t = the time in minutes required to force 20 cubic centimetres of water under the head a through the same stuff.

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[1] "Die wasserdichte Imprägnierung von Geweben für Hoereszwecke," Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1896, p. 675.

The value obtained for a depends to some extent upon the observer, the error not exceeding $\pm$ 3 centimetres, but t can be exactly determined.

An increase in a corresponds to a decrease in t, and a decrease in the former to an increase in the latter. If the error in finding a be $\pm$ x centimetre, t must equal $\frac{w}{a \pm x}$ if w is to remain constant. A large number of experiments show that, for heads immediately above or below a, w is approximately constant; thus t for these heads equals about $\frac{w}{a \pm x}$, and a slight error in a does not appreciably alter w.

W. B.

The Strength of Sewer Pipes and the Actual Earth-Pressure in Trenches. F. A. BARBOUR.

(Journal of the Association of Engineering Societies, New York, 1897, p. 193.)

In the breaking tests the pipes were laid in a trench, as in practice, and the pressure applied, by means of a hydraulic machine, to a platform resting on the filling over the pipe. Eight inches of earth was first put in the trench, then the pipe was laid lengthwise, underneath the hydraulic machine, and covered with earth, thoroughly rammed. A strong platform, the same length as the pipe, was laid on this filling, and the pressure of the hydraulic machine applied to it. The salt-glazed stoneware pipes experimented on varied in diameter from 6 inches to 24 inches, and in thickness from 0·7 inch to 1·5 inch. They cracked fairly uniformly with a pressure of 2,800 lbs. per linear foot.

In the tests of earth-pressure, the same machine was placed in the bottom of a deep trench and the earth was piled upon a platform resting on the plunger. The pressure was recorded by a pressure-gauge. The pressure of the filling on the pipe was thus found to vary from 70 per cent. of the weight of the filling material, with 1 foot of cover, to about 40 per cent., with 8·8 feet of cover, with sand and gravel.

A. W. B.

The Foundation of the Zwarte-Water Bridge at Hasselt.

D. P. AMEYDEN VAN DUYM.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1896–97, p. 46.)

The old timber bridge at Hasselt, built in 1828, was so worn and unsafe that a new one was urgently required. Great economy was, however, necessary, as for the new work of a total length of 100 metres only £5,500 were available.

The river bottom, which lies at about 4 metres (13 feet 3 inches) below mean surface-level, is of alluvial formation and soft. Instead of the usual pile foundation, open brick cylinders were employed. The shafts, two bricks thick, built on timber shoes, at the toe strengthened with a tee-bar, and suspended from a scaffold on piles, were lowered gradually to the river bottom, and the interior then removed with a vertical bucket-dredge worked by hand. The water-levels outside and inside were kept equal, so as to avoid rushes of mud in the soft soil, and the wells sunk to 3 metres or 4 metres below the bottom of the river. The central pier for the swing opening, elliptical, and 4·7 metres by 4·2 metres, is founded on a single well. The other piers are each founded on two wells side by side, with a rectangular space of 1·6 metre (5 feet 3 inches) wide between them, and the southern abutment on four square wells. All these wells have a core of concrete, and were sunk in from 5 days to 13 days, counting from the time of touching the river bottom to the reaching of the ultimate depth.

After a high tide in December, 1895, the river bottom was found scoured out near the southern abutment and the central piers. To prevent further damage, a rip-rap mound on a fascine mattress was sunk at these spots. The Paper contains plans, sections, and detail drawings.

H. S.

Coast Protection Works on the Baltic. KERNER.

(Centralblatt der Bauverwaltung, 1898, p. 25.)

The object of these works is to protect the coast of Mecklenburg in the neighbourhood of the town of Rostock, and to keep open the entrance of Warnemünde by trapping the sand borne along the coast by the prevailing current, and thus creating a beach.

Groynes have been erected along 4 kilometres (2·48 miles) of coast-line, carried out until the average depth of water at the head is about 2·5 metres (8·2 feet), and spaced not more than 1·5 times their length apart. To retain the sand, which is very fine, a special type of construction was adopted. Piles 20 centimetres (7·88 inches) in diameter were driven 1 metre (3·28 feet) pitch in two rows 75 centimetres (2·46 feet) apart, and weighted fascines were packed between the rows, secured in place by transverse timbers and longitudinal walings. The head of each groyne is weighted with stones, and the piles are sunk 5 feet to 6 feet 6 inches in the ground.

With hand-driving the total cost of the work was 46·8 marks per metre (42*s.* 10*d.* per yard), of which the labour of driving the piles absorbed 28·5 marks. In the later stages of the work, when electrical power had become available, this last item was reduced to 6·2 marks, with the aid of a twin pile-driver travelling on rails laid on the piles already driven.

As a result of the works, a sand beach has been formed 50 metres (164 feet) wide, and averaging 2 metres (6·56 feet) thick. Some of the groynes have been in place since 1889, and have successfully resisted the ice of severe winters.

Sketches of the twin pile-driver, and sections of the groynes and coast are given.

W. B.

Breakwater Construction on the American Coast.

L. Y. SCHERMERHORN, M. Am. Soc. C.E.

(Proceedings of the Engineers' Club of Philadelphia, 1897, p. 205.)

The Author reviews American practice in the design of breakwaters, and gives, amongst others, the section of those now in progress for the National Harbours of Refuge in Delaware Bay, Del., Sandy Bay, Mass., and that proposed at San Pedro Bay, Cal. These sections are approximately identical, the top width being 20 feet, with slopes of 1 in 0·7 down to low water, below which, on the exposed side, the slope is flattened to 1 in 3 for a depth of 12 or 15 feet, at which level wave-action is assumed to be negligible; consequently the slope is increased below that to 1 in 1·5. On the inside, from low water downward, the slope is 1 in 1·3. The tidal range varies from 3 feet to 8 feet.

A. W. B.

The New Sea-Wall at Schevening. T. A. LINDO.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1896–97, p. 141.)

The sandy eastern shore of the North Sea is subject to continual erosion, and in recent years the coast line retrograded to such an alarming extent that it became urgently necessary to defend the coast against further loss, especially near the village of Schevening and the bathing establishment, consisting of several important buildings. The construction of works under similar conditions at Norderney, Borkum, Blankenburg and Ostend, gave an indication of what might be practically efficient. The work under consideration consists of a concrete wall, 2·6 metres wide at the bottom and 0·85 at the top, with a stone face curved to a radius of 4 metres. The top of this wall lies at 7·36 metres above mean low water, and 3 metres above the highest known high tide. The foundation lies about level with mean high water. The toe of the wall is protected by an apron of basalt packing on a layer of broken brick covering an osier bed. The slope of this apron is 1 in 4, the top laying at 3·56 metres and the bottom at 1·86 metre above mean low water. The seaward edge of the slope rests against a row of

creosoted piles. The work is defended from the scour of lateral currents by three groins of osier beds covered by a basalt packing, from 80 to 85 metres long and 500 metres apart. Several inclined roads and stairways lead from the higher esplanade behind the wall to the beach, and an ornamental railing is fixed in the coping stones. The whole length of the work is 1,130 metres; it was executed in 8½ months at a total cost of 550,000 florins, or 490 florins per lineal metre, equal to about £36 17*s.* 6*d.* per lineal yard. Plans and sections illustrate the Paper.

H. S.

Improvements of the Harbour of Ymuiden.

N. A. M. VAN DEN THOORN.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1895–96, p. 6.)

Between the 1st July, 1894, and the same date of 1895, the operations for the improvement of the outer harbour of Ymuiden were more than usually important. The channel between the entrance and the locks was kept to its full depth of 9·5 metres (31 feet) below new Amsterdam datum, without having recourse to special efforts. The deepening from the locks eastward, to a depth of 9 metres below Amsterdam datum, with a width at bottom of 25 metres (82 feet) and slopes of 2 to 1, went on uninterruptedly. This sectional area is considered sufficient to allow ships of a length of 570 feet, a width of 50 feet, and a draught of 26 feet, to reach the roadstead at Amsterdam. The work was performed by two large suction dredgers, two bucket dredgers, and three smaller suction-dredge hopper barges. The total quantity removed during the year amounted to 632,280 cubic metres (827,022 cubic yards), at an average cost of about 7·36*d.* per cubic yard. The number of working days were, outside the piers, 131, and between the piers 245. After the storm with a high tide on 22nd December, 1894, the depth at the entrance diminished temporarily to 3·4 metres below Amsterdam datum, but this shallow was dredged away in a few days.

To this Paper several plans are added showing soundings in the years 1851, 1889 and 1895, and a diagram of the minimum depths in the channel.

H. S.

Lundy Island Lighthouse.

(Engineering, 7 January, 1898, p. 19 *et seq.*)

The Northern Lighthouse on Lundy Island has been fitted with a modern dioptric apparatus, giving two white flashes in quick succession every twenty seconds. The maximum intensity of the

beam is 121,000 candle-power for thick weather, reducible to 81,000 when the air is clear. The lamp is of the Trinity House type, with a number of concentric wicks, more or less of which can be used. Experience shows that this quality of light has the best fog-piercing properties. The apparatus, which was constructed by Messrs. Barbier and Bénard, consists of a first-order apparatus built up of two curved panels, having a pair of group-flashing Fresnel lenses in the centre of each, with a series of fifteen reflecting side prisms on each side, curved concentrically therewith. The apparatus and framework, weighing over 3½ tons, floats in a mercury trough, while the platform supporting the burner and attendants is fixed. A ring of rollers with vertical axes keep the revolving portion in position. The apparatus, which revolves once in forty seconds, is driven by weights through clockwork, and is controlled by a governor, which throws in more or less friction from cork rubbers. The mercury trough is carried on hydraulic rams, by which it can be lowered for examination, leaving the revolving apparatus resting on a second ring of rollers.

A. P. H.

The New Fish-Dock at Ymuiden. T. Baucke.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1895–96, p. 13.)

For the better accommodation of fishing-vessels calling at Ymuiden a tidal basin was constructed affording a safe shelter outside the locks. This basin, of an area of 6·5 hectares, or about 16 acres, is situated on the south side of the canal, with an open entrance channel leading into the outer harbour. A quay-wall forms the northern side of the quadrangular area. The other sides are sloped 2 to 1 above and 3 to 1 below mean low-water level, covered by a stone pitching on a fascine mattress. On the south side a pile jetty gives additional discharging space. The bottom of the dock lies at 5·1 metres below Amsterdam datum, or 4·18 metres below mean low water. The contract for the work completed amounted to £39,000. The value of fresh fish landed at Ymuiden in 1893 was over £50,000. Plans and sections of the work accompany the Paper.

H. S.

Canalization of the Rivers Moldau and Elbe. Mrasick.

(Allgemeine Bauzeitung, 1897, p. 127.)

Since 1896 a commission for carrying out the canalization of the Moldau and Elbe, between Prague and Aussig, has been appointed, and the working plans, sections, &c., for this "interlock" section

have been authorized to be carried out. This, the Klecan section, is the second on the Moldau below Prague, and was chosen to commence upon as being less difficult and requiring less time to complete than would be the case of the first section by Troja. The separate contracts for earthwork, ironwork for lock-gates, &c., and the needle-weir, also the construction of the lock-master's house were let in June, 1897, and the excavation was commenced in that month and steam excavators set to work. The article is illustrated by two large plates, the one giving a plan extending from Roztok past Klecanek to Husinec, being a stretch of river extending from the 207·5 kilometre to the 211 kilometre (below Budweis). The works now being carried out are shown upon this in red, and include a new channel, on the left bank of the Moldau, terminating in a lock at the lower end; a needle-weir at Klecanek; training-walls, &c. On the same plate is a longitudinal section of the river extending from the 200th kilometre to the 213th kilometre. The second plate gives a longitudinal section and plan of the needle-weir, a plan-section and cross-sections of the lock arrangements, and of the gates also of the lock-master's house. The needle-weir is divided by two piers into three bays of 38·90 metres, 38·90 metres, and 40·15 metres (127 feet 7 inches, 127 feet 7 inches, and 131 feet 9 inches), in addition there being another pier and a bay of 12 metres for the passage of rafts, also a fish-pass. The height from the sill to the top of the needles is about 4 metres. The lock arrangement comprises two chambers, one (Kammerschleuse) at the up-stream end, opening into the second, a larger and broader one for barge-traffic. The clear available length of the former is about 78 metres (256 feet), and width 10·85 metres (35 feet 6 inches), and of the latter 147 metres (482 feet) and 20 metres (65 feet 7 inches) respectively, so that, when using both in conjunction, there is an available length of 225 metres, which is sufficient to take a steam-tug and four large Elbe barges.

The top of the up-stream lock-gate is 3 metres (10 feet) above sill, and is at such a level as to be submerged at high floods, this condition being stipulated for by the authorities, in view of the lie of the surrounding district. There is a difference of 3·1 metres of water-level above and below lock.

D. G.

Statistics of the Gauging of Rivers in France. BRESSE.

(Annales des Ponts et Chaussées, part iii., 1897, p. 6.)

Acting under instructions from the administration, the Author has collected and tabulated gaugings of the highest, lowest and mean flows in each of the principal river-basins of France. In each basin he has particularly noted readings both of exceptional

floods and low water, and in all cases where, at any one station, the observations have been sufficiently numerous, he has from them deduced, under a graphic and algebraic form, the law governing the amount of flow.

The river-basins over which the observations have been taken are—The Seine, Meuse, Moselle, Loire, Garonne, Adour, Rhone, the rivers north of the Seine, and the rivers between the Seine and the Loire.

Tables of observations for each basin, and comparisons of results obtained from formulas and from actual observation, are given; and, in concluding, the Author discusses and sums up the advantages and disadvantages of the different methods of taking observations.

H. I. J.

The Ratios between Rainfall, Evaporation and Discharge.

H. E. DE BRUIN.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1896–97, p. 91.)

The Author endeavours to determine the ratio between rainfall and evaporation by consulting the registrations of rainfall in Bohemia and the quantities discharged by the river Elbe at Tetchen. Bohemia was selected because of the ideal circumstances obtaining there—an accurately-known area, with a single point of discharge, and information available over a period of several years. Grouping together periods of nearly equal rainfall to obtain mean quantities, these were compared with the discharge of the river during the same periods. In this way a formula was obtained to calculate the ratio between rainfall and evaporation, U denoting evaporation, r = rainfall, α and β certain coefficients, and C a constant. Then $U = \alpha\, r + C = \alpha\, r + \beta\, R$, in which R is the mean yearly precipitation. The values of $\alpha = 0 \cdot 47$ cubic metre, $\beta = 0 \cdot 258$ cubic metre, and $C = 8{,}900$ million, agree pretty closely with the result of the observations.

In the discussion on this communication, it was averred that the ratio between rainfall and evaporation was dependent on such a great number of factors that no fixed law could be deduced from a limited number of observations. As to the aspect of the question in the Netherlands, it was proved that the maximum rainfall and the maximum evaporation hardly ever coincided. That, moreover, subsoil currents had to be seriously considered, especially where it concerned the drainage of low-lying polders. Diagrams accompany the Paper.

H. S.

Lowering of Ground-Water Level by Means of Tube-Wells.

BREDTSCHNEIDER.

(Centralblatt der Bauverwaltung, 1898, pp. 73 and 88.)

This is an account of an experiment at Charlottenburg, where two overflow sewers were successfully laid in the dry, the level of the ground-water being temporarily lowered around them.

The trench was first excavated to the normal ground-water level, tubes 210 millimetres (8·26 inches) in diameter were then driven close along one side from 7 metres to 10 metres (22 feet to 33 feet) apart, and inside them the tube-wells 150 millimetres (5·9 inches) in diameter were placed. The wells in position, the larger tubes were drawn out, and suction-tubes of galvanized iron 100 millimetres (3·9 inches) in diameter dropped down. These suction-tubes from a number of wells were then connected to the main suction-pipe from the pumps, thus forming a group, the size of which depended on the head of water dealt with, the power of the pumping plant and the nature of the ground. Upon pumping, the level of the surrounding ground-water was lowered at the rate of about 1 metre (3·28 feet) in fifteen hours. While the length of sewer commanded by the first group of wells was being constructed a second group was prepared, so that the laying could proceed continuously.

The tube-wells were 13 metres (42·6 feet) long, made in two parts—the lower was of copper 2 millimetres (0·078 inch) thick, closed at the bottom and with its side riddled with holes; it was covered with fine copper gauze secured by twelve copper wires 3 millimetres (0·119 inch) thick, and over this again with netting of copper wire 1·5 millimetre (0·059 inch) in diameter with 100 millimetres (3·9 inches) mesh; the upper part was of galvanized iron screwed to the lower tube. They were sunk to such a depth that the top projected about 1 metre above the normal water-level.

Spigot- and socket-joints were used for the main suction-pipe, and made tight with rubber rings; it was 200 millimetres (7·8 inches) in diameter.

Three centrifugal pumps were used, of which two had a capacity of 2,500 cubic metres and one a capacity of 4,500 cubic metres for twenty-four hours. They were in general able to deal with eight tube-wells at once, but when approaching the Landwehr Canal only two could be managed. The ground was composed of sand of medium sharpness, and the water-level was lowered from 1 metre to 1·8 metre (3·28 feet to 5·90 feet).

Exclusive of material, the cost of draining the work by the foregoing method amounted to about 16,000 marks (£800) for the total length of 942 yards of sewer, while the estimated cost by the ordinary method of sheet piling and pumping was 41,000 marks (£2,050). The cost of materials, excepting engines and pumps, was 7,400 marks (£370). W. B.

A Water-Supply and System of Filtration. ALFONS HALKOWICH.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1898, p. 31.)

The Author describes the measures adopted to purify the water of the Danube and supply it for domestic use to a town of moderate size on its banks.

The town is divided naturally into an upper and a lower part. Water from the river flows to the pump through a channel filled with small stones, and is first forced up to a height of about 30 metres (98·4 feet) to a reservoir in the upper town, whence it flows down again through first a Bockmann, then a Worms sandstone, and finally through a battery of Berkefeld filters in the engine-house. By means of another pump some is now driven up into the main reservoir, supplying the lower and chief portion of the town by gravitation and the remainder direct into the upper town distributing pipes, or into a small reservoir commanding that part.

The entrance channel is intended to act as a strainer to the first pump, the Bockmann filter to prevent the main (Worms sandstone) filters becoming too rapidly choked up, and the Berkefeld filters to remove any bacilli which may have passed the latter.

To provide for fire, provision is also made for pumping filtered water direct into the pipes supplying the lower town, and, in cases of great emergency, for the supply of unfiltered water to all parts.

The Bockmann filters are two in number and are used alternately. Each consists of a cylindrical copper casing, near the top of which a longitudinal pipe is fixed, from which twenty filter-cells are hung. These cells are simply circular disks of wire-work 1 cm. (0·39 inch) thick, nearly as large in diameter as the casing, covered with close cotton stuff, and are in communication with the pipe carrying them. The water is introduced at the bottom of the casing, together with a quantity of powdered linden-wood charcoal, which, as the filter works, spreads itself over the cotton coverings; it passes into the cells, and then away through the pipe at the top. When clean the filters work with a pressure of 0·1 to 0·2 atmosphere, which, after six to eight hours' working, rises to 0·75 atmosphere, when the second filter is brought into action and the first cleaned.

The Worms sandstone filters are contained in two chambers, each having an area of 25 square metres (269 square feet) and holding four batteries of six plates each (system Fischer-Peters). They are of artificial stone, hollow, and the water passes from around them through the stone into a collecting pipe along the top of the plates, which are set on edge. The filters work with a head of 30 centimetres to 60 centimetres (0·98 foot to 1·96 foot) over the stones, and are not efficient until a fine deposit has been formed over them. Each plate should yield about 5 cubic metres (176 cubic feet) of filtered water for twenty-four hours. They are cleaned

by forcing the water through from inside, care being taken not to disturb the outer deposit.

Four Berkefeld filters[1] are provided, of which three are used at once; they work under a head of 2·6 atmospheres, and each filters about 4·5 cubic metres (159 cubic feet) of water per hour.

Three plates are given, showing diagrams of the distributing pipes, arrangement of reservoirs and filters, and detailed drawings of the latter.

W. B.

The Results obtained by Subsoil Drainage for the Supply of the Amsterdam Waterworks. J. VAN HASSELT.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1895–96, p. 40.)

The first Amsterdam waterworks obtain their supply from the sand-hills near Haarlem, part of the ridge between the North Sea and the marshy lands of the interior to the east. The supply is altogether dependent on the local rainfall, and up to 1890 this was gathered in open canals and ditches intersecting the collecting area of about 7,000 acres. In this year the Town Council of Amsterdam decided that an increased quantity should be obtained by means of subsoil drainage. The surface of the ground being very irregular in elevation, varying from 2 to 10 metres (33 feet) above Amsterdam datum, and the pressure of sand at such depths being considered too great for porous earthenware, iron pipes were laid down, with open socket-joints, in a packing of clean sea-shells. At several points the conduit is led through open wells for the observation of the flow through the pipes. For determining the levels of the ground-water, several vertical tubes are driven at the side of the conduit and at different distances from it. For an approximate estimate of the water so obtainable, a formula $I = a \frac{\theta^2}{D^5}$ was used, in which I = fall in millimetres per metre; θ quantity in cubic metres; D diameter of pipes in centimetres; and a a coefficient, in this case, 0·0025. Experience obtained since this subsoil drainage was started showed that the coefficient a calculated from the quantity of water pumped out, varied from 0·0114 to 0·0227. Notwithstanding the careful shell-packing around the pipes, large quantities of fine sand found their way into the conduit, from which it had to be removed through the open wells. It was found also that the quantity furnished by the covered drains was not larger than that from the open ditches, although the first tapped a lower level. The cost of covered drains was £10 per lineal metre against £5 for open work. A plan of the gathering ground is added to the Paper. H. S.

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[1] "Die Kieselguhr-Filter aus gebrannter Infusorien Erde von Berkefeld," Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1893, p. 206.

The Water-Supply from the Downs near Schevening for the Hague Waterworks. Th. Stang.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1895–96, p. 57.)

The water-supply for the Hague is obtained from deep-laid subsoil drainage of the sandy downs forming the sea coast. The advantages claimed for this system are: diminished risk of contamination, the tapping of a thicker stratum of sand, and opportunity of draining areas where open cuttings are not desirable. Even below heavily-manured fields, no traces of organic matter are found where the water has passed through a depth of 2 metres (6½ feet) of sand. The total length of the conduit and side branches is 13,074 metres. In 1895 the quantities supplied to the town varied between 23,000 and 18,500 cubic metres per 24 hours, and the infiltration into the conduit was therefore 1,761 cubic metres and 1,415 cubic metres per lineal metre respectively. In some places the conduit lies at a depth of from 12 to 20 metres below the surface, and the average cost of construction is about £4 per lineal metre (£3 12*s.* per yard). A drawing accompanies the Paper.

H. S.

A Fresh-Water Conduit across the Y at Amsterdam.

T. M. K. Pennink.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1896–97, p. 113.)

The fresh-water supply to the north shore of the Y at Amsterdam was conveyed through two leaden tubes sunk on the sea-bottom. These were continually subject to damage from the anchors of ships in the roadstead. To replace these a so-called cable-tube was employed, manufactured by Felten and Guillaume of Mulheim am Rhein. These leaden tubes, of 5 centimetres (2 inches) internal diameter and 4 millimetres (0·15 inch) thick, are enveloped with a steel wire spiral of 6 millimetres diameter covered with asphalt. This again is protected by a coat of hempen-rope and asphalt, bringing the total outside diameter up to 8 centimetres. Three of these tubes, each 410 metres long, are laid side by side in a groove dredged to 11·25 metres below Amsterdam datum. The total weight of cable-tubes of 30 tons was laid in about 25 minutes, and when in place the tubes were tested to a pressure of 50 atmospheres (300 lbs.) per square inch, and found to be perfectly tight.

H. S.

Coolgardie Goldfields Water-Supply.

(The Engineer, 21 January, 1898, p. 57.)

The Government of Western Australia has assumed the responsibility of supplying the inhabitants and industries of Coolgardie with an abundant water-supply. As the local rainfall is only 5 inches per annum, the scheme adopted consists in bringing water from the Greenmount range of mountains near the coast, where the rainfall is at least 20 inches annually. The Helena River, at an elevation of 320 feet above the sea-level, was found in every way a satisfactory source of supply; and an excellent site for a concrete dam has been selected, where a bank, 100 feet in height and 650 feet long, will form a reservoir 7 miles long, and capable of holding 4,620 million gallons. The service-reservoir will be 1,313 feet above the draw-off level at the storage-reservoir. It is proposed to supply 5 million gallons per day at Coolgardie, through a steel main, 30 inches diameter, by means of nine pumping-stations, the lifts at which, including friction in the main, vary from 185 feet to 420 feet, and the horse-power of the engines from 205 to 464; in all 2,881 horse-power. The estimated cost is 2½ million pounds sterling.

A. W. B.

Clarification of the Cologne Sewage Water.

Dr. Karl Fraenkel.

(Gesundheits-Ingenieur, November 15, 1897, p. 353.)

It was made a condition that, if the sewage of Cologne was to be discharged into the Rhine, it should undergo a previous process of clarification. Owing to the relatively large volume of river water, as compared with the total quantity of sewage to be dealt with, it was decided that simple deposition in tanks, without resort to chemical treatment, would suffice, but a controversy arose respecting the minimum rapidity of the flow through the tanks. The rate of movement in the tanks proposed by the Cologne authorities—namely, 3 feet per minute—was regarded by the Government, in the light of what had been prescribed in other cases—at Wiesbaden, Frankfort-on-Main, Essen and Dortmund—as much too rapid. The question in dispute was submitted by the authorities of Cologne, with the consent of the Government, to the Author, and he reports that it would not be expedient, for reasons given, to discharge raw sewage into the river, notwithstanding the fact that, owing to the great dilution, the average impurities in the Rhine would only be increased thereby, from 1 part in 5,000 to 1 in 4,975 parts. It is affirmed that no accurate data

are available to determine to what extent certain slight decreases in the velocity of the flow of sewage will augment the percentage of suspended matters which would be deposited in the tanks. The experiments of Lepsius at Frankfort led to the somewhat remarkable conclusion that the results of chemical precipitation and simple deposition were almost identical, and that both processes occasioned the separation of from 15 to 17 per cent. of the suspended impurities. The Author recommends that, in order to arrive at definite conclusions, two experimental tanks should be constructed, in which arrangements would be made for a series of trials. These trials would be conducted by experts, and the sewage water of Cologne would be passed through the tanks at varying speeds, from 5 inches per minute up to 4 feet per minute. Careful analyses would determine the composition of the sewage water, before and after treatment, and the amount of suspended matters removed will in each different case be accurately calculated. These tests should extend over two years, during which period frequent analyses of the sewage water should be undertaken, and experiments could also be conducted with respect to the best methods of dealing with the sludge.

G. R. R.

Dumping-Ground for Town Ashes and Rubbish at Giessen.

Dr. K. Kratz.

(Zeitschrift für Hygiene, vol. xxvi., 1898, p. 243.)

It is asserted that very few previous cases are recorded in which systematic investigations have been carried out of the nature of those undertaken by the Author; the work of Proskauer, however, served as his model. By reference to a plan, a description is given of the plot of land in the vicinity of Giessen, where the experiments were made. This land lies alongside the River Lahn, and had been used, since 1888, as a depot for all kinds of domestic rubbish and street-sweepings, as also for the refuse from a tile-works, and for the mud dredged out of the river. For the purpose of these investigations, which were in three distinct categories: (*a*) chemical; (*b*) physical and geological; and (*c*) bacteriological; eighteen bore-holes, arranged in four diverging lines, were drilled at nearly equal distances apart, so as to cover the whole area of the site. Two additional borings outside the area were used to check the results. The general depth was regulated by that at which natural cultivated soil was reached, but in some cases the borings were taken down some distance below the made ground. A detailed account is given of the methods of research adopted, and the results attained are set forth in a series of Tables; each boring being numbered from 1 to 20, and referred to on the plan. Some of the facts are shown in graphic form, and the temperatures

of the sub-soil at various depths, and the levels of the water in the soil encountered at each different date are likewise tabulated. A Table is given to indicate the amount of carbonic-acid gas in the air found in the soil, and the bacteriological analyses are also shown in Tables. Great fluctuations were observed in different parts of the site, in respect of the numbers of germs capable of development, and it was a singular fact that, in nearly all cases, the deeper layer of the made ground contained a bacillus, which induced death from tetanus when cultures were injected into mice. The Author likewise analyzes the results of the nitrification and denitrification of the soil by the agency of bacteria, acting upon nitrites in solution and upon solutions containing ammonic sulphate.

G. R. R.

A Description of a Section of the South African Railway.

A. WESTENBERG.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1896–97, p. 45.)

Between the stations of Waterval-Onder and Waterval-Boven, on the South African railway, the problem had to be solved to scale the rocky wall dividing the lower lands from the high "veldt" from which the Elandspruit river flows down to the east. The second station, distant from the first about 6 kilometers, lies 207·80 metres (680 feet) above it. The line follows, on the whole, the valley of the Elandspruit, advantage being taken as much as possible of the shoulders, or "kransen," of the rock walls; but near the top of the incline a tunnel through hard quartz rock could not be avoided, though only 237 metres long.

The gradients are steep, 1 in 50 being frequent, while between kilometer point 206 and the summit-level at 209·803 kilometers, the gradient of 1 in 20 over a distance of 3,753 metres is worked with a central-rack rail. To diminish as much as practicable the amount of earthwork, dry rubble retaining walls were used.

The price of cement at the spot was £1 5*s.* per barrel. The cost of excavation per cubic metre ranged from 3*s.* 6*d.* to 5*s.* in soft soil to 8*s.* for rock. Masonry in cement 1 to 3 came to £3 3*s.* to £3 15*s.* per cubic metre; dry rubble £1 to £1 5*s.* Stone pitching on slopes to 7*s.* 6*d.* or 10*s.* per square metre. The tunnel, with rubble walls and dressed-stone arch, cost £150 per lineal metre. The whole cost of this section amounted to £75,000. Plans and sections are added to the Paper.

H. S.

Gravel and Broken Stones as Ballast for Railways.

M. RUDELOFF.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1897, p. 279.)

Tests were made on five kinds of gravel and one sample of broken sandstone. The tests were intended to determine the resistance of the material against (1) blows by the rammer; (2) crumbling due to motion of the sleepers during passage of a train; (3) direct pressure; (4) weather and frost.

The original state of the material was estimated by determining the percentages of its weight having the following sizes of grain:—less than 6 millimetres, 6 to 12 millimetres, 12 to 18 millimetres, 18 to 25 millimetres, 25 to 32 millimetres, and 32 to 50 millimetres. The corresponding percentages were determined after the various experiments, and the order of value of the six different materials stated from the differences. The order of the six materials differs slightly for the four kinds of tests.

The methods of conducting the experiments are fully described, while the results and the deductions therefrom are given by twenty Tables and thirteen diagrams.

A. S.

Koppel's Portable Electric Railway. RICHARD MARKGRAF.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1898, p. 970.)

This is a short general account of the system touching on its advantages and relative economy.

The rails are laid in pairs already fixed to the sleepers in the usual way. The overhead conductor supports are ∩-shaped, and each is carried on an extended sleeper; on the straight they are placed about 25 metres (82 feet) apart, and in sharp curves in the centre of every rail length. The conductor is hung from the centre of the ∩, and, as the supports are not constructed to bear stress along the axis of the railway, is erected from a special carriage arranged to keep it always taut; a second carriage, following on the first from which the wire is unwound, holds the conductor while that leading travels on to the next support.

If the gauge exceeds 500 millimetres (1 foot 8 inches) the motor can be placed under a car which is used to carry paying load, thus saving the weight of a special car and obtaining greater adhesion. The mains from the central station are supported on portable posts which, except on curves, do not enter the ground, but rest on large circular bases. One main is connected to the overhead conductor, the other to both rails which form the return.

W. B.

Steam-Car for Branch Lines, New England Railroad, U.S.A.

(The Engineer, 24 December, 1897, p. 634.)

A steam-car was designed for the above railway, to avoid the expense of utilizing ordinary trains for handling light traffic on branch lines. The car is 65 feet long, with a bogie at each end, one of the latter carrying at its centre a vertical boiler working at 200 lbs. pressure, also two outside cylinders 12 inches diameter and 16 inches stroke, driving the rear axle of the bogie. The two axles are connected by coupling-rods. Round the bottom of the boiler is a race for the ball-bearing on which the car turns relatively to the bogie. On its trial trip the car maintained a speed of 30 miles an hour in ascending a gradient 3 miles long varying from 1 in 90 to 1 in 100, and hauling an ordinary passenger-car behind it.

A. W. B.

Railway Drawbridges over the Chicago Drainage Canal.

(Engineering News, New York, 2 December, 1897, p. 363.)

There will be four railway swing-bridges with a central pier for double line of rails and one for eight lines, which is not described in this article. The largest of the four, 474 feet 3½ inches long with an octagon pier 32 feet 6 inches diameter, is for the Chicago, Madison and Northern Railway. Each cantilever has nine panels, 25 feet 4 inches wide, 70 feet high at the pier and 30 feet at the ends; the central panel is 18 feet 3⅝ inches wide. The illustrations show that, with the exception of the top chords in the five highest panels, all chords and posts are riveted members riveted together at the junctions, but that all diagonal ties are eyebars with pins 4 inches to 11 inches diameter. The top chords are braced across. The weight of the bridge is transmitted to the turntable by means of two open-web cross-girders 8 feet 9 inches deep and 18 feet 3⅝ inches apart. Each rests, at points 18 feet 3⅝ inches apart, on the centre of four short plate girders 6 feet 7½ inches deep, which are fixed as chords to a circular plate-girder drum of the same depth and 28 feet diameter. The projecting ends of the cross girders carry the main girders 30 feet 3 inches apart. The drum has twenty-four radial lattice-girder arms, ending in a steel casting which turns on the upper part of a pivot fixed to the masonry, the lower part of which is reserved for the live ring, consisting of fifty-six cast-steel conical rollers, 18 inches diameter and 12 inches wide placed between two rings in the usual way. The toothed rack, 31 feet 4 inches diameter, is fixed to the lower roller-path and the pinion is fixed to the bridge.

The platform is constructed of plate-girders 4 feet 3 inches deep,

25 feet 4 inches apart, rail-bearers 3 feet 9 inches deep, 6 feet 6 inches apart for each line, and sleepers 9 feet by 8 inches by 8 inches, with inner guard-rails and outer guard-timbers. The ends of the bridge are lifted by steel wedges acted upon by compressed-air cylinders fixed longitudinally to the bridge. A vertical bolt, fixed to the bridge and dropping into a notch in the masonry, terminates the horizontal movement of the bridge. The foundation of the pier is an octagon of 50 feet diameter, made of concrete blocks, and is stepped off to 32 feet 6 inches, this being the diameter of the pier. The latter is of concrete faced with granite. The other bridges, two for the Atchison, Topeka and Santa Fé Railway, 364 feet 3½ inches and 322 feet 9½ inches long, and one for the Chicago Terminal Transfer Railway, 308 feet long, are of similar construction.

M. A. E.

Mechanical Traction. A. Barbet.

(Revue de Mécanique, November, 1897, p. 1033.)

The Author in a preface states that since the introduction of railways, the main roads of France have only served as a means to unite small towns, all traffic between large towns being carried by rail in preference to road. In districts where, for various reasons it would not pay to run branch lines, tramways along the roads offer the best means for an interchange of traffic. He points out that for this purpose mechanical is superior to horse-traction for three reasons:—(1) The smaller working expenses; (2) the extra power of the motors, which allows a trailer to be attached when the traffic requires it; (3) economy of time on the journeys.

He then enters into a detailed comparison, from the tractive point of view, between motor-cars running on rails and similar cars running on macadamised roads, and shows that while on the level the tractive force required per ton is nearly as 2 to 1 in favour of the former, on average gradients the difference is not so marked, being only as 4 to 3.

Section 4 deals with the conditions which a tramway motor should fulfil, viz.: (1) A flexible wheel-base, owing to the sharp curves met with on ordinary roads; (2) freedom from the emission of fumes, flames or clouds of steam; (3) the motor must be fixed to the same vehicle which carries the passengers; (4) the system must not require fixed apparatus, marring the appearance of the road, nor a disturbance of public installations already existing; (5) traction by the motor must be relatively economical.

A comparison is then made as to the relative advantages of a quick succession of small vehicles, as against larger vehicles running at longer intervals.

Section 6 deals with traction by compressed air, all applications

of which are founded upon the use of reservoirs on the vehicles, which are charged at suitable stations on the route. The Author points out that engineers are agreed as to the advantages of the system, the only diversity of opinion being in regard to the cost of working.

Section 7 treats of the economical value of compressed air, and deals with the difficulties encountered owing to the heat engendered in compression. In well-managed stations the amount of coal required per horse-power-hour has been found to be 1 kilogram (2·2 lbs.), and on routes having gradients up to 1 in 15, the amount of coal burnt per vehicle-kilometre (0·62 mile) does not exceed 2 kilograms (4·4 lbs.), the vehicles holding fifty-five passengers.

The Author in section 8 deals with the history of the use of compressed air for vehicles from the earliest records up to the present time, more particularly describing the inventions of Papin, Andraud, and Mékarski, whom he considers the inventors of the industry.

H. I. J.

The State Electric Railways, the Tramways and the Franz Josef Underground Railway at Pesth.

BRAUN.

(Elektrotechnische Zeitschrift, 1897, p. 545. 18 Figs.)

The Author gives a historical account of the rise and progress of Pesth, the population of which was 270,000 in 1869, and had risen in 1890 to 500,000. Owing to the foresight of the governing bodies, it came about that in 1889 the first electric street railway was opened, and three other lines were added before 1891. The first Pesth line is of special interest as being the earliest in which the underground conductor system was successfully used; it was laid down by Messrs. Siemens and Halske, and given over in 1891 to the Pesth Tramway Company. Its total length is 16·15 miles, and the gauge is 4 feet 8½ inches. Another line which had been worked by steam was fitted with the trolley system in 1893–4, this line is about 11·2 miles long. The underground system has two < shaped conductors fixed to cast-iron frames.

The channel is egg-shaped in section, 11 inches wide and 14·95 inches high. The bottom of the channel is 22·8 inches below the top of the rails, and does not interfere with the pipes in the streets, it is directly below one of the track rails which is made in two parts, with an open slot between them 1·18 inch wide. Lead-covered feeders supply the current to the conductors.

The power-station consisted at first of three 100-HP. compound condensing engines and three dynamos, but afterwards four 200-HP. engines were added, and then three 500-HP. engines

direct coupled to the dynamos; the total power is 2,600 HP., and there are thirteen water-tube boilers. There is also a battery serving for lighting the station, one car-shed shelters seventy-five motor-cars and six tow-cars, and another one hundred and thirty-two motor-cars and twenty summer cars. Some of the motors drive through gearing, and some through chains. The speeds vary from 6·2 miles per hour in the narrow streets of the city to 11·2 miles outside, and each car runs about 93 miles per day of sixteen hours. In 1896 19·8 million passengers were carried, the cars ran 2·3 million miles, and the receipts were £142,585, and a dividend of 12 per cent. was paid. On the trolley lines the rails are partly of the Haarman type and partly of the Vignoles type on wooden sleepers. The Budapest Street Railway Company is older than the Municipal concern, but only determined to apply electric power after the town authorities had already worked their own lines six years by that means. The conduit work is 18 miles long out of a total of 61·5 miles. The total of all the Pesth lines gives underground work 34·2 miles, overhead work 72·6 miles, total 106·8 miles. Hamburg is the only European city whose lines at all approach these figures. The Author draws attention to the underground system in Berlin on the Behrenstrasse Treptow branch. In Pesth the current returns partly by the rails and partly by a special bare conductor laid in the earth; 400 volts at the switchboard is allowed for overhead, and 350 volts for underground lines. On the Berlin-Treptow line there is a separate metallic return to avoid all chance of danger from vagabond currents. The passage from the trolley system to the underground work is perfectly simple. One of the stations has an output of 1,500 kilowatts, and the other of 2,500 kilowatts, there are two engines of 750 HP. and two of 350 HP.

The Franz Josef Underground Railway built in 1896 is an important part of the Pesth system. It was begun in August 1894, and completed for the Millennium exhibition; on its length of 4,050 yards there are eleven stations, and it is not a true tunnel, the roof being formed by the street pavement. It is 19·7 feet wide and 9 feet high. Asphalt was freely used to prevent infiltration of moisture. Details are given of the permanent-way construction and of the plant, which consists of four water-tube boilers and dynamos giving 300 volts and 1,100 amperes. The Paper closes with details of traffic and receipts.

E. R. D.

The Use of Electricity upon the Leipzig Tramways. Dr. Eisig.

(Elektrotechnische Zeitschrift, 1897, p. 441. 9 Figs.)

Formerly Leipzig was served by horse tramways worked by an English company, but on the 15th November, 1896, this work was taken over by a German company, and electricity introduced as the motive power by the Union Electric Company of Berlin. In April, 1896, the Gohlis Connewitz line was being worked by electricity from a temporary station. There are in all eight lines having a total length of 28·52 miles. The old rails have been replaced by Phœnix rails weighing 84 lbs. per yard, and provided with Chicago rail bonds and cross ties. The overhead construction is of the Thomson-Houston type; but there is also a separate line supplied with the material of the Allgemeine Elektricitäts Gesellschaft of Berlin, and the crossings of these two lines caused at first a good deal of trouble.

The overhead line is supplied from an underground circuit fed at twenty-three points, and divided into distinct parts; the cables are of the armoured type made at Duisburg. Each motor-car has seats for twenty persons and standing room for sixteen more, and weighs 7·25 tons, and all are of German build. Each motor develops 30 HP. and, inclusive of the gearing, weighs 1·1 ton. The cars are provided for the first time in Germany with air-brakes, of which details are given. As soon as a pressure of 37 lbs. is reached, the pump ceases to act; these brakes are only used when there are tow-cars. A speed of 7·5 miles per hour is permitted in town, 11 miles just outside, and 12·5 miles in the open country. About 185 motor-cars are now at work.

Details are given of the generating station, which is provided with five water-tube boilers of the Gehre type, with superheaters built at Chemnitz. They work at 150 lbs. pressure. The grates are of the Völcker type. Each boiler will evaporate 8,800 lbs. of water in regular work, and a maximum of 11,000 lbs. per hour; and the superheating varies according to load from 41° F. to 77° F. The coal is raised by an elevator and falls by gravity into the hoppers of the stoking apparatus; and the ashes are raised mechanically. A Reichling water-softener is used, and acts also as a water-heater, and a temperature of 176° F. is obtained. The condensed water is used, but the oil filtration does not seem perfect.

There are four compound vertical engines direct-coupled to the dynamos, and the total output is 2,100 HP., or 1,500 kilowatts; and particulars are given of the valve-gear, &c. All the engines work condensing. The two smaller engines each develop 300 HP. One surface-condenser serves the whole plant, and the air-pump is actuated by an electric motor. The condenser is designed for 19,800 lbs. of steam per hour, and gives a vacuum of 24·8 inches of mercury. The pressure of supply is 500 volts to 550 volts. The switchboard is built in two vertical parts,

joined by a part only slightly inclined to the horizontal, so that the total height is less than it would otherwise be. In this installation for the first time return cables have been used. There are twelve feeder points and nine return points in the system; 143 motor-cars and 45 trailing-cars are now in use.

E. R. D.

The Zurich Electric Tramway.

(The Engineer, 7 January, 1898, p. 5.)

The tramway is nearly 3 miles long, and consists of a single line of 1-metre gauge, with loops for passing, each 33 yards in length. The maximum gradient is 1 in 15. The contact wire is of copper, and 0·28 inch thick, and is suspended 18 feet above the ground-level on poles. The contact conduit is divided into four parts, so that, in case of any break on the line, the traffic can proceed on the other three divisions.

Each car weighs 3·8 tons, and is fitted with an electric motor, of the Oerlikon type, of 18 HP. The current is delivered jointly by a dynamo and accumulator, because the current required, though normally 80 amperes to 90 amperes, varies from nothing to 200 amperes. In this manner the engine is always enabled to run under the most favourable conditions. There are two vertical compound engines, each of 90 HP., which run at 240 revolutions per minute, and two dynamos, each of 66 kilowatts, worked by leather belts from the engines, at a speed of 450 revolutions per minute. The accumulators consist of 300 Tudor elements, of 245 ampere-hours capacity.

A. W. B.

The Extension of the Basle Tramway System. O. Löwit.

(Schweizerische Bauzeitung, 1897, pp. 132 *et seq.* 25 Figs.)

The income from the first electric tramway in 1895 was 10·2*d.* and in 1896 it was 9·03*d.* per car-mile. These results were so encouraging that in April and May, 1897, four new lines were opened for traffic. The original line was meant for a three-minute service, but a six-minute service was used, as the narrow street would not permit of more cars, therefore a second line was absolutely necessary to accommodate the traffic. On the new lines the grades are severe, 1 in 13½, with a curve of 32·7 yards radius. Details concerning the Phœnix and the Haarman rails used and of the overhead work are given. The posts in the city are made of Mannesmann steel tubes, while those in the suburbs are of lattice work.

The power station was originally designed to allow of increase, and now the full complement of four Cornish boilers, each 28·86 feet long by 5·9 feet diameter, are used.

There are three steam dynamos; all the engines are of the tandem compound horizontal type, two driving by belt, and the third, just put down, driving direct, develops a maximum output of 350 B.HP. at 85 revolutions; the dynamo gives 550 volts.

The consumption of gas-coke for June and July, 1897, was at the rate of 2·13 lbs. per HP.-hour, the coke cost 17*s.* 6*d.* per ton. The total cost of power without interest or sinking fund for capital was 0·53*d.* per car-mile. A large new car-shed and workshops have been built just outside the town; the shed has eight tracks, each capable of holding six cars. All the machine tools in the workshops are driven by a 13-HP. electric motor, working at 500 volts; it also drives by a magnetic coupling a direct-current dynamo giving 100 volts to 140 volts for the lighting of the premises. The whole construction is 265·7 feet long by 98·4 feet wide.

With regard to the rolling stock, Messrs. Siemens and Halske supplied for the line at the outset cars provided with a single large motor placed in the centre and connected to the two axles by chains and chain-wheels; this has proved such a satisfactory arrangement that it has been adhered to for all the extensions with the exception of the Kohlenberg line, where the gradients are 1 in 13½, and there it was considered best to use cars with two motors driving by gearing. The motor case is built of Krupp's cast steel in two parts, and has 4 poles, of which only two are wound, the other two being consequent poles. The armatures are of the drum type with 87 grooves and an 87 part commutator (*sic*). The complete 20-HP. motor weighs 1,606 lbs.; the average efficiency on the level is 79·5 per cent. and on the steepest gradients with average load about 85·5 per cent. The gear wheels are steel, with teeth of fine pitch, and the reduction is 1:5·5, but these wheels only last about six months, while the chain-gear wheels last three to four years. Diagrams and a detailed description of the controlling switch-gear are given. The rolling stock consists of 28 single motor-cars, 14 double motor-cars and four tow-cars, and of these 28 cars are used on week days and 35 to 38 cars on Sundays. The takings average 9·9*d.* to 10·4*d.* per car-mile, and the expenses 5·6*d.* per car-mile. About 16,000 passengers are carried daily, and the figure rose to 27,587 on one Sunday, exclusive of season-ticket holders.

E. R. D.

The Neuchâtel-St. Blaise Electric Tramway. R. B. Ritter.

(L'Industrie Électrique, 1897, pp. 496–520.)

The line lately equipped for electric traction between Neuchâtel and St. Blaise has features of considerable interest, since the supply of current for its operation is taken from the already existing high-pressure mains, distributing at a pressure of 4,000 volts three-phase. From this tension static transformers are employed to reduce the current to one of 337 volts; rotary transformers then change it to one of 550 volts continuous for use on the tramway in the ordinary fashion. There is nothing very characteristic in the overhead wire structure or other working parts of the tramway; a half-hourly service is maintained, and a good load-diagram is secured, even with this infrequent service, by means of a battery of accumulators which not only acts as a regulator but on emergency would suffice for a reserve. It consists of 300 cells of the Tudor type, with a capacity equal to 60 amperes. The cars have seating capacity for twenty-eight places, and are each provided with two 12-HP. motors. They are both lighted and heated by electricity. The street-lighting current is also supplied from the same source—thirty lamps being erected in six series of five lamps.

F. B. L.

On Heavy Flange-Rails with Angle Fishplates.

C. P. Sandberg, M. Inst. C.E.

(Engineering, 14 January, 1898.)

The unsatisfactory state generally of the permanent way on the Continent laid with too light flange rails as compared with the English type of road, led the Author to design in 1886 the "Goliath" 100-lbs. flange rail. In order to make a fair practical comparison and test under the same conditions of the two types of road, the Furness Railway Company agreed to lay down on their main line one mile of Goliath type of road side by side with their usual permanent way.

This has now been down seven years, and, so far, has given general satisfaction. The cost of laying down and of maintaining the road is about the same for the two systems, and the run over the Goliath rail is, if anything, smoother, and there is less vibration than with the English type. There is also, on the London, Chatham and Dover Railway in the Penge Tunnel, one mile laid with a 110 lbs. flange-rail, which gives a smooth run.

With regard to wear, the Goliath rail has only worn off $\frac{3}{32}$ inch, or only three lbs. per yard loss of weight, and carried 1,000,000 tons per year, or during the seven years a total of 7,000,000 tons, with a maximum axle-load of 16 tons. Thus, with using only

½ inch of the wearing-surface, it would carry at least 30,000,000 tons.

The rails were made by the Barrow Hematite Steel Company from steel of a medium hardness, containing 0·43 per cent. of carbon. Although this trial is on a small scale and on a straight line, and has only yet extended over a period of seven years, it tends to prove :—

(1) That excessive hardness of rail-steel is not required, as the wearing results with the above medium hard rails are very satisfactory.

(2) That while admitting the English type of road is the strongest for heavy traffic, railways laid with flange rails of greater weight and good section, combined with a well-designed rail-joint, could then approach very nearly to the high standard of English road without changing their type.

A rail weighing 100 lbs. per yard is no longer considered an abnormal weight for heavy traffic and high speed; and the Author has now designed a 120-lbs. rail section with wide flange that can be easily rolled and laid without baseplate direct on the sleepers, which would be equal in cost to an 85-lbs. bull-headed rail with chair. This would give the most elastic road for smooth run at high speed, be economical in maintenance, and carry an axle-load of 20 tons. Seeing that these new rail sections with wider flanges can be rolled with the greatest ease, the costly and complicated baseplates are not required; but their value should be put into the rail itself, thereby obtaining a better road without increased cost.

All users of flange-rails must be indebted to the Furness Railway Company for making this trial, inasmuch that there was never any intention of changing the English type of road, but rather of improving Continental types, which have been generally constructed with too light rails, often of inferior designs of section and rail-joint. The same reason does not exist now for saving steel as formerly, as the price has gone down from about £12 to £4 per ton, and even half of the latter can eventually be recouped by selling the old rails. Moreover, the cost of maintenance of road as well as rolling-stock would be greatly reduced by the use of heavier rails generally, while the increased traffic capacity obtainable with a heavier axle-load would further help to repay the extra first cost.

In fact, the heavier flange-rail would not only make high speed safe with a more elastic run when laid without baseplates, but it would also reduce the cost of carrying heavy goods by permitting heavier engines and heavier trucks to be used.

It has been recently asserted[1] that one of the reasons for the smooth running at high speed noticeable on some American railways is the use of flanged rails; and the further advantage is claimed for this type of permanent way, that it reduces the working expenses, and enables freights to be lowered.

[1] *The Times*, "Notes on American Railways," March, 1898.

Hand Locking-Frame for Points and Signals at Intermediate Railway Stations. F. BLAZECK.

(Organ für die Fortschritte des Eisenbahnwesens, 1897, p. 216.)

The Author goes at great length into the present system of working interlocking points and signals, indicates the defects, and shows how the apparatus described remedies them.

The locking-frame advocated is adapted for intermediate stations with not more than six sidings, and obviates the necessity for electrical block-signals. The chief point is the construction and manipulation of the interlocking parts. The point- and signal-levers are mounted in a frame; at the end of this frame is a lever-handle for working the locking-bar; this latter is cylindrical, and carries two rows of stops set at different angles. The lever of the locking-bar is capable of movements in two planes; in one it slides the bar backward or forward, and in the other it turns the bar through a segment of a circle. The result is that the locking-bar, besides its normal position, is capable of six distinct motions. In its normal position it blocks the up and down main lines, and frees all other point- and signal-levers; in any other position it frees the points of any particular siding while blocking all others.

The whole system is clearly explained, and fully illustrated by two sheets of details. It has been in operation at two intermediate stations near Lemberg, and has given perfect satisfaction.

W. A. B.

Theory of the Stability of Locomotives. J. NADAL.

(Annales des Ponts et Chaussées, part iii., 1897, p. 271.)

The movement of a locomotive upon the rails is not a uniform one, by reason of the play of the road, the play existing between the various parts of the engine itself, and the movement of the frame upon the springs. The movement of translation is thus accompanied by accessory movements, viz.:—

(1) Oscillation of the weight hung on the springs.

(2) Rotation around a vertical axis passing through the centre of gravity.

(3) Displacement of the centre of gravity from side to side.

The Author, in sixteen sections, studies the laws and conditions governing these accessory movements, which he divides into two parts:—

(1) Oscillations of the frame upon the springs.

(2) Winding or sinuous movements.

The principal sections treat of and fully discuss subdivisions of these parts, viz., the influence of the compression and extension of

the springs, the inequalities of the road, the reaction of the cross-head upon the guides; the influence of (1) the difference in the flexibility of the springs, (2) the number of axles, (3) of bogies; the influence of the sinuous movement of the frame upon the speed; the forces which tend to produce a rotary movement of the frame around a vertical axis; the side friction of the flanges; the force exerted laterally upon the rails through the sinuous movements; the friction on curves; and the influence of the tender in preventing side movement.

In conclusion the Author points out that the speed plays the most important part in the amount of side movement, and though there are engines which can with safety attain a speed of 120 kilometres an hour and upwards, there are others for which the question of security demands a limit of speed.

H. I. J.

"Mastodon" Locomotive.

(Railroad Gazette, New York, vol. xxxvii., 1897, p. 578.)

This engine, which was made by the Brooks Locomotive Works for the Montana service of the Great Northern Railway, U.S.A., is the heaviest of the ordinary pattern yet constructed. The two cylinders are 21 inches in diameter by 34 inches stroke. The engine weighs 95 tons without tender, or 138 tons with the tender. The boiler is 87 inches in diameter at the largest point, and 78 inches at the smallest, the length between tube-plates being 13 feet $10\frac{3}{8}$ inches. The firebox, which is stayed on the Belpaire system, and has an inclined top, is 124 inches long, and $40\frac{1}{2}$ inches wide. It is, as is usual in America, of steel. The centre line of the boiler is 9 feet 5 inches above the rail-level. The funnel is very short, to come within the American loading-gauge of 15 feet 6 inches in height. The grate area is 34 square feet, and the heating surface, 3,280 square feet. The driving-wheels, of which there are four pair, are 55 inches in diameter, the heaviest load on one pair being 20 tons.

A. P. H.

Adjustable Bearings for Locomotive Axles.

(Organ für die Fortschritte des Eisenbahnwesens, 1898, p. 9.)

The fittings for these axle-boxes have been designed by Mr. O. Busse, and supplied by him to the Danish State Railways, of which he is chief locomotive superintendent; they are extremely simple, and, being of the same outer dimensions as the ordinary ones, may easily be substituted for them.

The peculiar features of these bearings consist in the shape of the brasses, packing pieces and wedges. The brasses are in two halves, the division being at the top; a rectangular recess in the one half fits a corresponding projection in the other. The packing pieces are L-shaped and have a recess and projection similar to those in the brasses but on opposite sides, so that each overlaps both brasses on their upper surface. The brasses encircle the journal to the extent of 300° of the circumference, their surface being thus from 60 per cent. to 70 per cent. greater than usual, and covering those portions of the journal which are most exposed to unequal and irregular shocks and strains. These axle-boxes have been in constant use on ten passenger and goods locomotives of the Danish State Railways for a considerable period, and have given such satisfactory results that the whole of the thirty-seven express passenger locomotives now under construction are, by order of the Direction, to be fitted with them.

The set of illustrations accompanying this Paper fully explain all the details.

W. A. B.

The New Heilmann Electric Locomotive. E. HOSPITALIER.

(L'Industrie Électrique, 1897, p. 489.)

The first electric locomotive of the Heilmann type—forming practically a complete central station upon wheels—was built and experimented with in 1894.[1] Since then further experiments have been made, and changes of a somewhat radical nature effected in the design; the present article is a description of the new locomotive, tests of which were made in the month of November, 1897, upon the Western of France Railway Company's main line between Paris and Mantes.

In the new locomotive the three-crank vertical engine originally used (set transversely across the frame) is replaced by a six-crank twelve-cylinder compound vertical engine, fixed parallel with the frame, and coupled direct to a large dynamo generator at each end. The cranks are set at 120°, and each system of three cranks is so designed as to mutually nullify the vibration effects. This main engine indicates approximately 1,350 HP.; the boiler is of the ordinary locomotive type with Belpaire copper fire-box, and about 8 tons of water for feed purposes are carried in side tanks. For long runs a tender is used carrying 20 tons of water and weighing 45 tons in working order.

The machinery end of the locomotive frame runs in front, being mounted upon an eight-wheeled bogie, each axle of which is provided with its own electric motor; the boiler is at the rear end of the locomotive frame mounted upon a similar eight-wheeled bogie.

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[1] Minutes of Proceedings Inst. C.E., vol. cxiii. p. 481; vol. cxvi. p. 486.

The total length between buffers is nearly 62 feet; the bogie centres are 37 feet 8 inches, and the wheel-base of each bogie about 13 feet 8 inches. The total weight of the entire locomotive in working order is approximately 125 tons.

In this article the Author, after giving these particulars, proceeds to criticise the design, and concludes that, with the traction coefficients ordinarily accepted, the new locomotive cannot possibly maintain the high speeds anticipated (80 to 100 miles per hour) in actual service. He thinks that at the utmost it will only draw a net train-load of 100 tons at 65 miles per hour mean speed.

F. B. L.

Standard-Gauge Electrical Locomotive with Two Driving Wheels.

(Organ für die Fortschritte des Eisenbahnwesens, 1897, p. 241.)

This compact locomotive is designed for passenger, goods and station traffic. The extreme dimensions are within those of the normal profile for State railways, so that these locomotives can be run as wagons over the whole Continental system. Each axle is driven by a separate motor, and a train-load of 120 tons can be drawn at the rate of 30 miles an hour on a level road.

The frame consists primarily of two deep wrought-iron plate-girders, with angle-iron flanges, braces and stiffeners carrying side brackets, which help to support the drivers' shelter; this covers the greater portion of the floor area, leaving, however, at each end a platform 3 feet wide. The motors and all the working parts are beneath the floor-level, cased in and protected from dirt; access to them is obtained through suitable trap-doors. The brake-handle, which works all four brakes simultaneously, is in a convenient position in the shelter. The conductors are overhead. Two 0·0315-inch hard copper wires, 6 inches apart, are supported on brackets fixed to standards placed by the side of the rails at distances varying from 130 feet to 260 feet. From the conductors the current passes to a couple of 3-foot bronze rollers, resting on carriage springs fixed to the roof of the cab. The rails provide for the return current. The axles and framing receive the weight of the motors in such a manner that only one-eighth of it is not supported on springs. The motion of the armature is transmitted to the axles by spur wheels, one of phosphor bronze, the other of cast steel. With a pressure of 500 volts and current of 110 amperes the number of revolutions is 840 per minute, equal to 84 HP. per motor. Two of these locomotives are at present under construction. The Paper is fully illustrated.

W. A. B.

Accidents caused by the bursting of Boiler Tubes.

C. Walckenar.

(Annales des Ponts et Chaussées, part iii., 1897, p. 312.)

From 1888–1896 the French Department of Public Works has investigated fifteen cases, outside those relating to locomotives, in which boiler tubes have burst, causing either death or serious injury. The Author describes and discusses fully the details of these cases, dividing them into, (1) tubes from 6 centimetres to 9 centimetres (2½ inches to 3½ inches) in diameter, (2) tubes over 10 centimetres (4 inches) in diameter. In no case were the tubes of steel or iron, fourteen cases occurring with brass and one with copper tubes.

In the seven cases occurring to tubes under 10 centimetres in diameter the cause has been either wear or corrosion, in addition to alteration of the metal caused by the action of the fire. Four of the boilers were constructed with interior furnaces, two were semi-tubular, and one of marine type. In three cases failure occurred during ordinary working, and four during a stoppage of the engine. In three of the latter either the fire-box or smoke-box door had previously been opened.

In the eight cases relating to tubes over 10 centimetres in diameter the first occurred during the trial of a boiler made entirely of copper, which was totally unfit for the pressure it was worked at. The seven other failures all happened to horizontal semi-tubular boilers with brass smoke-tubes, of which the first six form a series almost precisely similar, the pressures ranging from 5 kilograms to 7 kilograms (30 lbs. to 45 lbs. per square inch). Failure always occurred on the furnace side, and generally affected one tube only. The seventh case was that of a horizontal tubular boiler in which several of the original brass tubes had been working for 14 years, and in one of these the failure occurred.

The Author in concluding points out that the use of brass tubes, especially of the larger sizes, sooner or later leads to failure through the wasting of the metal under the action of the hot gases. He condemns the practice of leaving open the fire- or smoke-box doors, and advocates large and well-ventilated boiler-houses provided with easy exits.

The Paper is illustrated with a sheet of ten figures, giving sections of boiler-houses and views of ruptured tubes.

H. I. J.

Importance of Details in the Construction of Axle-Boxes.

GOSSEREZ, Rolling Stock Inspector of the Eastern Railway.

(Revue générale des Chemins de fer, 1897, p. 200.)

Of the type of axle-box employed on the Eastern Railway since 1878, 89,176 were in use in January, 1897. With an increase in the diameter of the axles, due to the increase in the weight of the rolling stock, these axle-boxes had been expanded, while the construction has been unaltered. These larger ones were found to leak and waste oil, consequently a series of experiments was made, and the following modifications introduced, viz., the lower orifices in the dust-guard chamber were done away with, and a leather washer inserted below the pressure spring, the division between the dust-guard chamber and the oil-reservoir was partially removed. The outer lip of the oil-cup was lowered, reducing the level of the oil in the reservoir. An internal horizontal rib was inserted in the front of the grease-box, and the lap of the joint between upper and lower halves of axle-box increased. Axle-boxes with these alterations were tested with the old pattern ones on the same carriages, and gave such satisfactory results as to cleanliness and saving in oil that they have been permanently adopted. It is evident, the Author remarks, from these experiments that the slightest fault in construction may materially increase the working expenses of a railway, especially in parts exposed to so much wear and tear as axle-boxes.

The Paper is illustrated with numerous diagrams and two sheets of detailed drawings.

W. A. B.

A Central Axle-Box for Locomotive Crank-Axles. LE TOUZÉ.

(Revue Générale des Chemins de fer, 1897, p. 263.)

The Author advocates the adoption of a third axle-box in the case of locomotives fitted with journals outside the driving-wheels. Horn-plates of special construction are provided, and the brasses of the journal-box are in three pieces; there are also extra guide-blocks, so disposed as to admit of the most exact adjustment with the two outer axle-boxes.

In the calculations of the various strains to which the axles are exposed, the following assumptions are made:—That the weight on the axles is constant and the speed uniform; the consideration of accidental forces is omitted, which is the more allowable as the aim in view is merely a comparison of two cases, and not an absolute determination of the strains occurring. The left-hand crank is assumed to be in its lowest vertical position, the right-hand one exactly horizontal. All strains acting on the axle are calculated first in the case of two journals, and then in the case of

three, and the results are given in two sets of Tables. A couple of diagrams of these strains also show at a glance the advantage of the employment of a third axle-box in the case under consideration.

The axle referred to in this article was of the type belonging to locomotives Nos. 1,002 to 1,005 of the Eastern Railway of France, designed and constructed in 1892, two of which are provided with compound and two with non-compound cylinders. The principal dimensions of these are given, the total working-load being 45·476 kilograms. A practical proof of the advantage of a third journal-box is further demonstrated by the fact that the Eastern Railway have, at the present moment, 149 locomotives fitted in this manner. The Author considers it may be of some value to append a copy of the instructions issued to the locomotive department regarding the proper adjustment of the central axle-box, and the amount of pressure to be allowed on it in regulating the same.[1]

W. A. B.

Sliding Axle for Locomotives. O. Busse.

(Organ für die Fortschritte des Eisenbahnwesens, 1897, p. 213.)

This axle is self-adjusting on curves, and a uniform distribution of the load on the bearings is in all cases secured.

The special feature of the invention lies in the mounting. The frame bears on a massive pivot working in a bronze bearing; to this latter are bolted a couple of cross springs; the ends of these springs rest on shoes suspended by hinged bolts from the cross girder which carries the journal-boxes. These suspenders incline outwards and can swing sideways.

The draw-bars are hinged to lugs on the inner side of the journal-boxes, and are free to move in a horizontal plane; they also incline outwards. The effect of this construction is that when one wheel is raised by the superelevation of the outer rail on a curve, the suspending bolts on that side tend to assume a vertical position, those on the opposite side being forced further out of the perpendicular. This the weight of the locomotive counteracts and restores things to their normal position as soon as it is off the curve, the load on each journal remaining constant. The outward inclination of the draw-bars produces a similar effect. All liability to rocking is prevented, and the travelling is remarkably smooth. Prolonged observations of the working of locomotives thus fitted on the Danish State Railways have proved the efficiency of the system, and led to its general adoption.

The Paper is furnished with six illustrations which, with the letter-press, fully explain the construction.

W. A. B.

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[1] Central axle-boxes have been in use for the past ten years on the London and North Western Railway; also the Great Western.—Sec. Inst. C.E.

Adjustable Window-Blind for Railway Carriages. F. HUILLIER.

(Revue générale des Chemins de fer, 1897, p. 282.)

A window-blind of this description, invented by Mr. Van Craéyénest, workshop foreman of the Western Railway of France, was shown at the Rouen Exhibition in 1896. The Author in this Paper describes an improvement designed by Mr. Jacquet, sub-inspector of rolling stock on the same railway. The blind is attached to an ordinary spring-roller at the top, and the other end is wound once round a rod. This rod is provided at each end with a small eye-bolt through which a metal guide-rod or a strong cord passes. In the centre of the rod there is a short lever with a weight attached to it.

The pull of the spring-roller tends to turn the rod, and the eye-bolts at each end consequently grip the cord, or catch in the notches cut at suitable distances in the guide-rods. Thus the blind may be fixed at any height. When it is to be raised or lowered, all that is necessary is to pull the weight attached to the lever; this brings the eye-bolts into a horizontal position, which enables them to move freely up or down on the side guides. The construction is very simple, and at very small cost can be fitted to any description of window-blind.

W. A. B.

Railway-Carriage Windows without Frames. R. KÜHN.

(Organ für die Fortschritte des Eisenbahnwesens, 1897, p. 238.)

There are many objections to the ordinary window-sashes of wood or metal. The frame obstructs light, does not fit close, rattles, and warps; none of these defects exist in the frameless window described in this Paper, which is illustrated with sections at the top, bottom and sides.

The plate-glass employed is 0·315 inch thick, the edges are rounded and polished, and slide in felt-lined grooves in the door-frame; the lower end is gripped by the lips of a metal rail with rubber protection; to this rail is attached a broad band which passes over a roller and carries a counterweight that balances the sheet glass and allows it to slide freely up and down. A hole drilled through the plate-glass admits of a handle with rubber washers being screwed on in a suitable position. The fitting is both air- and water-tight; the glass is easily taken out when required, and the cost is less than that of the ordinary sashes. These windows have in practice proved most serviceable; they run easily, never rattle, retain warmth better than the thin glass windows, always present a clean appearance, and, with ordinary use, are practically indestructible.

W. A. B.

An Electric Travelling Crane at the St. Triphon Quarries.

(Schweizerische Bauzeitung, 1898, p 4. 1 Fig.)

The marble quarries of St. Triphon are on the right bank of the Rhone between Aigle and Bex, and within 700 yards of the Jura Simplon railway station of Ollon St. Triphon. From the end of the eighteenth century until 1860 the stone was worked by drilling and blasting, but since that date on the terrace system. The Author gives details of the method of quarrying until lately in use, which consisted of drilling and splitting by means of wedges. Recently machinery has been added.

The apparatus for cutting the rock consists of an endless steel rope travelling at a speed of 16 feet to 19 feet per second, which saws the rock by the application of water and siliceous sand. The rope passes over suitable sheaves carried by posts, whose position can be adjusted. A similar apparatus is used for dressing the blocks. The rope consists of three strands, and it appears that a length of 100 feet can be cut.

Transport of the blocks is effected by a travelling crane. The track is 98·4 feet wide, and is carried alongside the cliff for a distance of 87 yards. The travelling carriage runs upon a cross-girder, having a total length of 155 feet as it is carried over the track as a cantilever at each end. Current is furnished at low pressure by a dynamo direct coupled to a high-tension motor developing about 20 HP.; the dynamo also supplies current for lighting. The crane is designed to lift 30 tons at a speed of 26 feet per minute, and it travels at the same speed; it was built at Vevey. It was tested with a load of 33 tons, and has given satisfaction.

E. R. D.

Regulations as to Compressed-Gas Reservoirs.

(Moniteur Industriel, 1897, p. 309.)

The French Minister of Public Works having appointed a Commission to report if the use of compressed-air or gas reservoirs demanded special regulations, the investigations made by them are given in this Paper.

They have collected administrative, statistical, and technical information from railways and users of compressed gas, from which it appears that reservoirs of compressed gas, as used by railways for lighting purposes, are tested in a similar manner and under the same regulations as those for steam. Reservoirs of compressed air for locomotives, of which the capacity does not exceed 200 litres (8 cubic feet), are not subject to official tests.

Small reservoirs are usually charged from accumulators, which are kept at their normal pressure either by arrangements which stop the pumps when the given pressure is reached, or by safety-

valves operating through a column of mercury or other means. The compressed-gas reservoirs for railway-lighting use are not usually provided with safety-valves, and the pressure is ascertained by pressure-gauges fixed to them.

The conclusions arrived at by the Commission, after careful investigations into the causes of danger, and comparison with the conditions governing the use of steam reservoirs, are: (1) That, in the present position of the industry, special regulations are not necessary, a recommendation being, however, made to users, that all reservoirs should undergo a preliminary test, and those of large capacity be provided with safety-valves; (2) That if the use of compressed air and gas should considerably increase, regulations, somewhat on the lines of the above recommendations, should be drawn up; but, before drafting same, it would be necessary to obtain more details of the practical working of these reservoirs and the conditions governing their use.

H. I. J.

On Blast-Furnace Gas as Môtive Power in Gas-Engines.

LENCAUCHEZ.

(Comptes rendus de la Société de l'Industrie Minérale, 1897, p. 207.)

The direct use of blast-furnace gas for producing power has been under trial for two and a half years at Seraing, in a small engine of 8 HP., a larger one of 150 HP. being under construction; and at Hörde a group of motors, with four cylinders collectively of 900 HP., had been at work in November 1897 for two months. As regards the latter the Author is informed that as a motor it works well, but frequent stoppages for cleaning on account of the dust brought in by the gas have been necessary, and that when the gas is perfectly clean the power that was expected has not been realized. At Seraing the results have been as follows:—

1. The gas employed is comparatively "rich," varying in calorific value at 30 in pressure and 59° F. between 961 and 1,084 calories per metre cube, or an average of 997 (112 B.T.U. per cubic foot).

2. The expenditure per HP.-hour is between 4·03 and 5·3 cubic metres, averaging 4·665 cubic metres or the whole of the gas obtainable from 1 kilogram of coke.

3. The initial compression necessary is 8½ kilograms, or 9½ atmospheres (142 lbs. per square inch).

4. The proper temperature of the waste water from the jacket is 75° C. (167° F.).

5. The water required for washing the furnace-gas amounts to 1·4 cubic metre (276 gallons) per HP.-hour.

6. The explosive pressures, as well as the work realized, have varied within rather wide limits as follows:—

Explosive pressure in kilograms per 0^{m2} 00·01[1] . .	13·7	7·5	5·3
Mean „ „ „ „ . .	2·6	2·2	1·75
Indicated HP. „ „ „ . .	6·45	5·45	4·25

7. The efficiency realized is 76·6 per cent., or 4·8 brake-HP.

8. The speed of rotation within the range of the regulator is from 180 to 200 revolutions per minute, while the extremes in good working condition may be between 95 and 250 revolutions.

From these data the Author concludes that the initial compression of the gas must be increased proportionately with its inferiority in heating power, and that while 3 kilograms per square centimetre is sufficient with illuminating gas, mixed producer gas requires 5 kilograms, coke-gas 7 kilograms, and blast-furnace gas 8½ kilograms, and the corresponding expenditure of heat for these different fuels is per HP.-hour—

Fuel	Cal. Power per Cubic Metre.	Quantity.	Total Heating Power.
	Calories.	Cubic Metres.	Calories.
Illuminating gas	5,350	0·600	3,210
Mixed (anthracite and steam) gas . . .	1,460	1·460	3,766
Coke-gas	1,200	2·950	3,980
Blast-furnace gas	997	4·665	4,641

It will be seen from these figures that the heat expenditure per unit of power increases in a more rapid proportion than the simple inverse ratio of the heating power, 0·6 kilogram of anthracite in the mixed gas produced being equivalent to 1 kilogram of coke in the blast furnace. Blast-furnace gas is, however, a sub product, 36 per cent. of its heating value having been already realized in the furnace, so that the effective expenditure of coke for subsequent use is only 100 − 36 = 64 per cent., or 0·640 kilogram per HP.

In good average practice the thermal utilization of a good steam-engine is only 10 per cent., or one-half of that obtainable for an average gas-motor, or an economy of 50 per cent. in favour of the latter, and it must also be remembered that blast-furnace gas is a very inferior steam fuel, being for equal heating power only about one-half of that of good coal; for if the latter gives 9 kilograms of steam per 8,000 calories, the same number of calories contained in 8 cubic metres of gas will not give more than 4·5 kilograms, so that on a final result the Author considers that blast-furnace gas for the production of power will be four times more useful in gas-engines than in the best combination of steam-engines and boilers.

H. B.

[1] *Sic* in original; it means per square centimetre.

Experiments on the Compression of Steam.

V. A. E. Dwelshauvers-Dery.

(Revue de Mécanique, October, 1897, p. 925.)

The Author states that the question "as to whether it is economical to close the exhaust port before the end of the return stroke of the piston," though often discussed, has never been the subject of a properly conducted research. He quotes at length from an article by Mr. Marcel Desprez, who expresses the opinion that compression is indispensable to obtain a maximum economical efficiency; and also investigates a theorem enunciated by Zeuner, which states that, "With complete expansion, complete compression annuls the harmful effect of clearance space."

To test these theories a series of trials with an experimental non-condensing engine, working at 80 lbs. pressure, have been carried out at the University of Liége, by the Author and his students, full details of which are described. The principal points investigated were, the most economical point of compression, the influence of initial condensation, and the alterations due to the engine running at different speeds; and the conclusions arrived at from these trials are generally opposed to the theory quoted.

Diagrams taken from the engine are shown, and also a specimen Table, giving the various results arrived at from a 6-days' trial, the principal results of which are also graphically shown.

H. I. J.

The "Nuss" Water-Purifier for Steam-Boilers.

Carl Morgenstern.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes. 1898, p. 30.)

The "Nuss" water-purifier is made in three designs, in each of which the separation of the impurities is effected at the boiler pressure.

In the first design, which also acts as feed-heater, the precipitation takes place inside the boiler; an internal pipe leads from the lowest part of the boiler, outside to the filter, and the filtered water is conveyed by another pipe back to the boiler. A small injector keeps up a constant circulation through the filter.

In the second design, precipitation of impurities is effected before the feed-water is led inside the boiler.

In the third design, the soda or lime feed, feed-heater, jet condenser, settling chamber and filter are all combined in one apparatus.

The arrangements of the apparatus are clearly shown by drawings. A. S.

Power Transmission for Small Machines.

(Bulletin de la Société Industrielle de Mulhouse, 1897, p. 297.)

The chief points investigated by the Author were, first the comparative advantages of friction gear, and next the advisability of using leather bands of a trapezoidal section upon grooved pulleys. With regard to the former, he made experiments both with ordinary friction pulleys in different material and with the Sellers friction-disk arrangement. A Table (of which the following forms part) is given of his results:—

Effective HP.	Pressure in Lbs.	Adhesion Coefficient.	Total Efficiency (including Motor).	Pressure in Lbs.	Adhesion Coefficient.	Total Efficiency (including Motor).
0·5	50	0·264	0·52	36	0·361	0·52
1·0	84	0·305	0·65	60	0·424	0·64
1·5	110	0·347	0·73	90	0·421	0·72
2·0	150	0·339	0·71	120	0·420	0·76
2·5	180	0·352	0·71	150	0·418	0·73

The Sellers friction-disk arrangement he found to give much less satisfactory results than those above.

As for the method of employing trapezoidal-section leather bands, he considers it may be safely and advantageously used up to as much as 10 HP. The coefficient of adhesion (subject to further verification) appears to be about 0·463. The angle adopted for the sides of the trapezoid is one of 40°.

Illustrations are given to show the methods adopted, and suitable dimensions.

F. B. L.

Undulating Pump.

(Advance proof. Transactions of the American Society of Mechanical Engineers, November, 1897.)

Two pumps of this description have been erected at Chicago to raise the water of the Chicago river a height of from 3 to 8 feet into the Illinois and Michigan Canal, in order to reverse the flow in the river for drainage purposes. Each pump consists of three rectangular pistons, having a combined rectilinear and oscillating motion inside a trunk or case of rectangular section. Each piston is provided with two perpendicular arms. The ends of each pair of these receive a circular motion from one of three cranks set at an angle of 120°. At the two lines where the edges of the three pistons are in juxtaposition, sliding crossheads, travelling in guides across the case, connect neighbouring pistons and

prevent leakage between them. The three cranks are driven by an engine, and produce a wave-like motion of the pistons, the effect of which is to propel forward any water which enters the case with great force. The pump is double-acting, and delivers on both the up and down stroke, being positive in action. It has no suction or delivery valves. The internal dimensions of the rectangular case are 4 feet 3 inches broad, 2 feet 8 inches high, and 24 feet long. The efficiency of the pump and engine combined is 41·7 per cent., giving a probable pump efficiency of 45·4 per cent.

A. P. H.

Dynamometric Governor for High-Speed Steam-Engines.

F. Bayle.

(Revue Maritime et Coloniale, 1897, p. 478.)

The Author discusses the causes of the fluctuation of speed of a steam-engine, and the modes of reducing the fluctuation to a minimum, especially for a steam-engine driving a dynamo. He concludes that the most rational solution is got by interposing a dynamometric governor between the engine and the dynamo.

A dynamometric governor should consist essentially of two parts: (1) an elastic coupling, the distortion of which is used to operate the steam-valve; (2) a special apparatus determining the relation between the power transmitted and the valve-opening necessary to give a constant speed, or a speed varying according to a certain given law.

He then describes a governor which has been used for dynamo-driving in the French Navy. An elastic coupling of two springs formed by a number of Belleville washers threaded on two rods, connects the fly-wheel of the engine and the shaft of the dynamo. The relative motion of the engine and dynamo shafts is transmitted by means of an epicyclic train to a collar working on a screw on one of the shafts, such that the longitudinal motion of the collar is proportional to the effort transmitted. The steam-valve used is a lantern-valve, which is opened or closed by a slight rotation of its spindle and controlled by a slotted link, in which the end of a rod connected with the epicyclic gear moves.

The end of this rod is guided in a curved path, the form of which is determined as follows:—The lantern-valve being disconnected from the elastic coupling, the engine is set to run light at the required speed. The load on the engine is augmented and the lantern-valve is carefully opened until the original speed is again obtained, and the position of its slotted lever is noted. This being done for a number of engine-loads, the form of the guide-path is easily determined.

The Paper is accompanied by numerous illustrations showing the details of the governor.

A. S.

Gas and Petroleum Motors. G. Richard.

(Revue de Mécanique, November, 1897, p. 1060.)

The Author in this Paper describes the details of construction of the vaporizers, regulating devices, firing mechanism, distribution and cooling arrangements, of leading types of petroleum motors, the whole being illustrated by seventy detail drawings.

He divides vaporizers into three distinct classes: (1) vaporizers separate from the cylinder and heated by lamps; (2) vaporizers separate from the cylinder and heated by the exhaust gases; (3) vaporizers forming a continuation of the cylinder and heated by the firing of the air and gas. The vaporizers described and illustrated are those of Hornsby, Nagler, Spiel, Barker, Gardner, Swiderski and Schwicher, Merlin, Peugeot, Arrol and Raymond, and the electrical vaporizers of Southey and Rowbotham.

The regulating of the supply of petroleum is effected by either a pump with a variable stroke controlled by a governor, an arrangement controlling the size of the oil admission hole, or a slide-valve with varying stroke. The arrangements shown are those of Hornsby, Bousfield, Davies, Holroyd-Smith, Gardner, Société Civil and De Dion.

The distribution generally does not differ from that of gas-engines, being usually effected by gas-, air- and exhaust-valves worked by cams, the arrangements shown being those of Peugeot, Lorenz and Bickerton.

The firing is usually effected by ignition-tubes heated by an external lamp, the systems illustrated being those of Crossley, Priestman, Roots, and Clayton and Shuttleworth.

Cooling arrangements, by means of side wings cast on the cylinder and cooled by the external air, or by a series of pipes surrounding the cylinder, and an induced current of air, are used by De Dion and Hornsby for auto-motors.

Various attempts have been made to free the exhaust gases from their smell, most of which are very ineffective, and, in addition, cause back-pressure in the cylinder. The best of those tried is that of Bedson and Hamilton, of which a drawing and description are given.

H. I. J.

Kay's Acetylene-Gas Generator.

(The Engineer, 31 December, 1897, p. 656.)

The producer consists of a small gas-holder, to which generating cylinders are attached at the sides, in an inclined position, to facilitate charging the carbide and discharging the residue.

The gas given off is conveyed upwards from the generators through a pipe and down again through condensers, in which the temperature is reduced from 120° F. to 70° F., drip-wells being

provided for the condensible hydrocarbons and the impurities; the pipe then passes upwards within the water-tank, and the outlet pipe passes from the gas-holder downwards.

The water for generating the gas is supplied from the gas-holder, through a series of injectors, into the carbide, in a fine spray.

A governing valve regulates the supply of water to the generators according to the number of lights burning, and cuts off the supply when no lights are in use. The pressure in the apparatus cannot exceed 1½ inch of water.

A. W. B.

On Acetylene Burners. Alf. Weber.

(Schweizerische Bauzeitung, 1898, p. 31. 4 Figs.)

In this Paper the Author gives an account of results obtained by him in testing various types of acetylene gas-burners at the works of C. Weber-Landolt at Menziken. All burners without exception become clogged with soot after a short time. A Bunsen grease spot photometer with Hefner Alteneck normal lamp was used, and a meter by Brunt & Co. of Paris.

The calcium carbide used came from Neuhausen.

The first series of tests were made with a Bray burner, No. 0000, and the results are shown in the form of a curve; the pressures varied from 0·197 inch to 1·763 inch of water; the most favourable was found to be 1·38 inch, and the light was 39·9 English standard candles per cubic foot of gas used per hour. At that pressure the actual quantity used per hour was 0·96 cubic foot, and the actual candle-power 38·2.

According to Ahrens and Castellani, the theoretical lighting value of the gas is 41·9 candles per cubic foot per hour. The Author tested thirteen types of two-hole burners, and found the Bray 0000 to give the highest efficiency, 96 per cent.

All burners of the two-hole type begin to produce soot and smoke after twenty hours' use. The Author then describes Dr. Billwiller's burner with two openings, whose axes are at right angles to each other. This burner gives a smokeless flame; the best pressure for the gas is from 2 inches to 2·3 inches of water; the efficiency is 79 per cent., and the consumption of gas is 0·77 cubic foot per hour, with 25·2 candle-power, being equivalent to a production of 32·7 candle-power per cubic foot of gas burnt per hour. The Billwiller burners are being made by the Acetylene Gas Company of Basle.

The Author believes that the Billwiller burner could attain an efficiency of 92 per cent. by slight alterations in form, and although this is not so high as the efficiency of the Bray No. 0000 when new, the latter is useless, owing to the soot produced.

E. R. D.

Accidents to Grindstones and Emery-Wheels. C. PFAFF.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1898, p. 25.)

The Author discusses the old methods of mounting grindstones on their axles and the causes of bursting. He then describes, with illustrations, modern methods of mounting, by means of which even if the stone broke up, the fragments would be prevented from flying apart. Guards to prevent injury to workmen from pieces becoming detached are also described.

A. S.

Furnace for Burning Green Sugar-Cane.

(Le Génie Civil, 6 November, 1897, p. 12.)

Mr. Leon Colson, manager of the Gol works, has devoted much time to the perfecting of a furnace which should be capable of burning cane taken direct from the mills. From experiments made, he has found that for each ton of cane crushed per hour there should be in the furnaces 40 square metres to 50 square metres (431 square feet to 539 square feet) of heating surface, 0·2 square metre (2·15 square feet) of chimney area for a height of 25 metres to 30 metres (82 feet to 98 feet), 0·5 square metre (5·5 square feet) of grate area.

Tubular boilers are preferred on account of their evaporating power and their economy of fuel. The disadvantage of their being unsuited for a variable consumption of steam is obviated by the use of a large reservoir of steam and water placed over each boiler.

The furnace described is 3·5 metres (11·4 feet) × 2·6 metres (8·5 feet), and has a semi-circular arch, the crown of which is 3·48 metres (11·4 feet) above the fire-bars. A supplementary furnace for burning wood or straw is separated from it by a flue which leads to each boiler, and baffle-plates are arranged in such a manner as to force the gases and flames to mix.

The fire-bars are slightly inclined, and the green cane, brought by a conveyor, is fed into the furnace at the top end by two hoppers. The ashes are abundant, and it is necessary to clear them from the flues once in twenty-four hours, and from the fire-bars at least twice every twenty-four hours.

With the old furnaces and boilers the average quantity of wood burnt per ton of cane crushed was 41 kilograms (90·4 lbs.), and of cane straw 30 kilograms (66·1 lbs.). The green cane contains 53 per cent. to 55 per cent., and the cane straw dried in the sun 25 per cent. to 35 per cent. of moisture, according to the weather.

A trial of sixteen days and nights' run without stopping has been made, during which time 3,311 tons of cane were crushed.

All the green cane was burnt, and in addition 52,940 kilograms (52 tons) of wood, which is equal to 16 kilograms (35·3 lbs.) per ton of cane crushed. During this trial the evaporation was regular and active, and the draught perfect. The fire-bars were cleaned twice a day, and the boiler-tubes were also cleaned by means of a steam-jet.

To obtain the best results the following four conditions must be observed:—

(1) To have as large an arch as possible in the furnace.

(2) To have a very strong draught.

(3) To well combine the gases and flames before they reach the boilers.

(4) To have a separate supplementary furnace for burning wood or straw.

With the old furnaces and boilers the Gol works employed, for each twelve hours' shift, nine stokers, including the chief, thirteen wagoners, nine mules, and eight women and four men for drying the cane. With the new furnaces five men only, including the chief, are required.

H. I. J.

Auriferous Conglomerate of the Transvaal. G. F. Becker.

(American Journal of Science, 1898, p. 193.)

The nature of the auriferous conglomerate of the Witwatersrand goldfield is a subject of great interest to geologists, who, however, have arrived at various conclusions. By most it is regarded as a marine littoral deposit; but some observers have held that the gold is detrital, others that it is a chemical precipitate from the ocean in which the beds were laid down, and others again that the metal reached the uplifted but uncemented gravel in solution. These theories are criticized in great detail by the Author. None of them are, he considers, free from objection. By the theory he advocates himself, however, no noteworthy features are left unexplained, his view being that the deposits are of marine placer origin. At the time of the formation of the conglomerate the Witwatersrand lay along the shore of an extensive auriferous area, presenting belt after belt of quartz veins running nearly parallel to the coast. The drainage cutting across this area brought down auriferous detritus and formed beach placers such as occur on the Pacific Coast of North America and in New Zealand. Subsequently the conglomerate was upheaved, injected with dykes, and metamorphosed. According to this theory the auriferous beds should be found to extend along a line of ancient coast bounding an area in which gold-bearing veins were rich and numerous. How large this area may have been, and how long its ancient coast was, it is as yet impossible to say.

B. H. B.

The Peletan-Clerici Method of Gold Extraction. L. PELETAN.

(Revue Universelle des Mines, vol. xl., 1897, p. 178.)

This process combines the principle of cyanide solution with that of electrolytic reduction of the dissolved metals, the latter being collected in mercury as amalgam, and both operations are carried out simultaneously. The dissolving and precipitating vessel, a flat-bottomed circular vat about 8 feet in diameter and 3½ feet deep, is provided with a central shaft and four cross arms carrying a series of steel blades forming an agitator, while the bottom is lined with an amalgamated copper plate having a thin layer of liquid mercury above it. This is put into electric connection with a dynamo as the kathode, the anode being formed by the blades of the agitator, which are kept at a level of about 2 inches above the mercury surface. The material to be treated, which should be crushed dry and to any degree of fineness between 40 to 80-mesh sieve, is charged, in quantities of about 2½ tons, with 0·1 per cent. of potassium cyanide, 0·2 to 1·0 per cent. of sodium chloride, and when necessary with sodium peroxide to the extent of about 10 per cent. of the weight of the cyanide, the whole being dissolved in water. The working of the charge takes about twelve hours, the finer particles of gold dissolved by the cyanide liquor being reduced by the current and deposited on the kathode, while coarser pieces fall through the bath and dissolve in the liquid mercury. The loss of the latter metal is stated not to exceed about 3 ozs. per ton of mineral treated. Under the most favourable circumstances about 86 per cent. of the assay value of the ore has been recovered. The cost of treatment is given at about 5*s.* per ton, two-thirds of that amount representing the outlay on chemicals, and the remainder in about equal proportions that on labour and motive power. This is, however, in addition to the cost of crushing. For a plant treating about 100 tons per day about 30 HP. is required, about one-third of which is taken by the dynamo, one-third by the agitators of the twenty dissolving vats, and one-third by the lifts and pumps, the weight of the solutions being very much less than in the method of cyanide solution by percolation, and not exceeding 80 to 100 per cent. of that of the mineral. The cost of such a plant is given at about £2,400.

The process has been adopted at eight different establishments in the Rocky Mountain and Pacific mining districts in North America, and five other plants are in process of erection in Colorado. It has also been successfully tried in Chili and Russia.

H. B.

Coal-Mining at Great Depths in Belgium.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1897, p. 686.)

At the Henriette shaft at Flenu workings have been opened at a depth of 1,150 metres (3,772 feet). After passing through a depth of about 300 metres of disturbed ground below the former bottom workings at 650 metres, a feeder of salt-water giving about 18 tons in twenty-four hours was cut in driving, and caused the works to be stopped for some years until the new winding engine was erected. This has two horizontal cylinders 43·12 inches diameter and 82·32 inches stroke, working expansively with steam at four atmospheres, the expansions being controlled by the regulator and making 65·4 revolutions during the lift. The total load is 6 tons, namely, 3 tons of coal and six tubs and cage together 3 tons. Originally it was proposed to use flat steel wire ropes, but it was found impossible to design these so as to avoid a negative moment at the end of the lift, and aloe fibre has been substituted. The total length of the rope for a depth of 1,200 metres is 1,350 metres, and the section tapers from 420 × 48·5 millimetres at the drum to 225 × 27·5 millimetres at the cage end, giving an average weight of 11 kilograms per metre and a total weight of 14,850 kilograms. The minimum radius of winding is 1·62 metre, and the maximum 4·22 metres, the moments of the load being 17,116 metre-kilograms at the bottom and 405 metre-kilograms at the surface. The water, which had considerably diminished during the time that the working was stopped, having been taken out by the winding engine, exploring drifts have been commenced in two seams at 1,100 and 1,150 metres depth, but the total length driven is under 500 metres at present. The coal on the face is very hot, but owing to the powerful ventilation the work goes on regularly, about 18,000 cubic feet of air per minute being supplied to each end. Under these conditions, when the surface temperature is 32° F. that of the shaft bottom is 60° F., and that of the return air 75·2° F., and a rise at the surface to 45 degrees only brings up that at the bottom to 62° F. With a greater extent of ground open it is, however, likely that the return air will become much warmer. The rock temperature when first cut in the sinking was from 113 to 118 degrees. The coal gives off a large amount of gas, so that the length driven is restricted to 1 metre per day.

H. B.

The Hongay Coalfield in Annam. F. Brard.

(Bulletin de la Société de l'Industrie Minérale, 1897, p. 155.)

Hongay is a small island of carboniferous limestone in the bay of Along, situated on a prolongation of the axis of elevation of the Island of Hainan. The coal-bearing area extends in a nearly

continuous line bearing N. 70° E., S. 70° W., the principal working places being at Hatou, about 7 miles eastward, and Nagotna, 2½ miles north of Hongay, on the coast where the shipping port has been established. At Nagotna a pit has been commenced intended to work three seams 6 feet, 13 feet, and 12 to 13 feet thick respectively, with a comparatively high dip of 30° to 50°, which it is intended to reach by cross cutting. At Hatou two seams are met with, a small one known as the floor seam, and the great seam between 150 and 200 feet thick, including several beds of shale and sandstone, which reduce the actual thickness of coal by about one-third, or to 100 to 130 feet. Notwithstanding this great thickness the coal is entirely free from shale partings, so that even the slack contains only from 6 to 6½ per cent. of ash—a proportion that is reduced in the large coal to between 1·8 and 3·3 per cent. The workings on the seam, which has a south-westerly dip varying from 15° to 46°, are entirely open in two large quarries separated from each other by the ridge of a hill. The surface is stripped by hand, or in some instances a steam-navvy is used, and the coal when laid bare is removed in terraces, whose joint length is now from 2,000 to 2,200 yards, the breadth of terrace being about 16 feet. The higher terraces, being above the level of the loading shoot, are served by self-acting inclined planes, but engine-power is required for those below that point. A Worthington pumping-engine, placed about 13 feet above the lowest working, is used for drainage. This has a capacity of 250 gallons per minute, and is kept at work continuously during the two rainy months, July and August, when the rainfall sometimes exceeds 20 inches per day. At Charlot, about 1½ mile west of Hatou, the outcrop of what appears to be the same seam has been discovered, dipping easterly. It therefore seems probable that the coal is continuous over the intermediate ground, which represents a reserve of about 50,000,000 tons, about 8,000,000 being sufficiently proved by the present workings. The coal for both groups of mines is drawn by railway to the shipping place at Hongay, where screening arrangements and a large shipping pier equipped with hydraulic cranes have been erected, where ships drawing 20 feet of water can come alongside at the lowest equinoctial spring tides, the loading capacity being about 1,500 tons in 12 hours. The coal, a semi-anthracite, almost identical in composition with the best South Wales steam coal, being only slightly less coherent, is sold at $5 for screened, and $2·30 for slack, free on board, which at present rates correspond to 4*s.* 2*d.* and 8*s.* 9*d.* per ton respectively. The output for 1897 was about 130,000 tons, which was distributed to all the East Asiatic ports between Singapore and Shanghai. At Hong Kong briquette works have been established for dealing with the slack, which makes serviceable patent fuel when mixed with 10 per cent. of Japanese bituminous coal.

H. B.

The Brown Coal-handling Plant.

(Railroad Gazette, New York, vol. xxxvii. 1897, p. 291.)

This plant, which is in use at various ports on Lake Erie, for transferring the contents of large railway coal-cars to the holds of ships, has, as its principle, the tipping of an entire car sideways, instead of dropping its contents through floor hoppers. The car, on entering the tipple frame, is secured by hydraulic clamps, having a long range of adjustment. Fixed on the tipple frame are six hoppers. As the car is tipped sideways, the coal fills these hoppers, which, in the act of tipping, are brought over six boxes capable of holding 6 tons each, and supported on special cars. As the tipple frame begins to return, the doors closing the hoppers are automatically opened, allowing the coal to slide into the boxes. When the tipple frame has returned to its original position, the hopper-doors automatically close and lock themselves ready for the next charge. The hydraulic clamps being released, the empty car is pushed away and replaced by a full one. The six boxes with coal are now lifted separately by one of two overhead travelling cranes, and lowered into the hold of the ship, the contents being emptied through a drop bottom when in the desired position, so as to minimise breakage of coal. Only ten men are required to work the plant, which can load 4,000 tons in ten hours.

A. P. H

The Saint Etienne Colliery Railways. Perrin.

(Bulletin de la Société de l'Industrie Minérale, 1898, p. 5.)

The Saint Etienne Colliery Company, whose mines are situated in the suburb of Le Soleil, adjoining the town of St. Etienne on the eastern side, has four principal groups of pits at work upon seams varying from 10 to 20 feet in thickness, at depths between 325 and 700 yards below the surface. As these seams generally lie at low angles and have bad roofs, it has been found necessary to work them by the method of complete excavation and stowage, with earth and stone sent down from the surface, to the extent of 50 per cent. of the mineral removed. The quarries that had previously furnished this material had in course of time been worked down to the surface level, and as extensions could only be had at prohibitive prices, the ground being for the most part built over, it was decided to open a new quarry on the side of the hill at Eparre, about 1½ mile to the eastward of the most distant group of pits, that of Villiers and Du Treuil, which are also the deepest (500 and 625 metres), where sufficient material could be obtained for the whole period of the Company's working, with connections

by a system of railways, of 1-metre gauge, with all the pits, the coal-washing and briquette works, coke ovens and other surface establishments, the maximum gradient being fixed at 1 in 50 and the minimum radius of curvature at 50 metres; the lines being laid out as much as possible within the Company's property to avoid excessive payments for compensation and surface damage, and all streets and surface railways to be crossed in tunnels. These conditions have necessitated rather a circuitous trace, the main line from the Treuil pits to the quarry being 3,062 metres (1·9 mile) long, and the whole system, including seven short branches, 4,614 metres (2·9 miles). There are six tunnels on the main line varying in length from 42 to 483 metres, and together making up more than one-third of its length (1,146 out of 3,062 metres); the average cost of the substructure being about £10 per yard in the tunnels and 15*s.* per yard in the open-air sections.

The new quarry occupies a surface of about 40 acres with a rise of about 70 metres, which has been laid out in six terraces averaging 10 metres high and 25 metres breadth of floor, the length at each level being about 600 metres, giving an available supply of 1,000 tubs, of 16½ cwt. each, per day for 50 years. The broken stuff, consisting of one-third hard stone lumps, and two-thirds smalls, and earth, loaded into the pit tubs at the quarry faces, is lowered by batches of six on self-acting inclined planes, laid with two lines of rails, one of 1½-metre gauge for the loaded platform wagon and the second of 800 millimetres for the counterpoise, weighing 9 tons, which raises the empty vehicles and tubs. There are two inclines placed parallel to each other, about 16 feet apart, one serving the north and the other the south side of the quarry. They are generally similar, except that one is slightly steeper than the other, with a gradient of 427 instead of 400 millimetres per metre. The lower ends of these inclines connect with an insetting place formed as a circular gallery round the Eparre pumping-engine pit, 26 metres below ground, at the head of the long Eparre tunnel. Here the tubs are loaded upon platform wagons, each carrying six, which are made up into trains of six, weighing about 50 tons gross, with a net load of filled tubs of 37·8 tons. The trains drawn by locomotives weighing 10 tons empty, or 12·9 tons in running order, at a speed of about 10 miles per hour, are distributed to the different pits as required. About 3 minutes are required for sending down a set of tubs for the quarry and returning the empties, so that in continuous work twenty sets or 120 tubs per hour, 960 for each incline, or 1,920 for both for the minimum working period of 8 hours, can be supplied—a quantity which is considerably in excess of the present requirements, which are met by 1,000 to 1,200 per diem. The railway service is performed by three locomotives, a similar number being kept in reserve and changed at intervals of 3 months. In year Oct. 1896, to Oct. 1897, 8,009 trains were run, carrying 288,324 tubs over 38,960 kilometres, or a daily average of 26·6 hours, 961 tubs, and

a distance of 129·9 kilometres, the last figures corresponding to 43·3 kilometres per engine per day. The transport cost, including wages, fuel, stores, and maintenance of the line, works out to about 1·3*d.* per ton of material carried—about one-fourth being chargeable to the quarry and three-fourths to the railway. The total cost of the works, which were about 3 years under construction, was—

	£
For the railways	29,060
„ quarry	6,312
	35,372

The whole of the details of construction are very fully described in the Paper, which covers 150 pages, with eleven folio plates of illustrations.

H. B.

The Sondra Gas-Spring in Thuringia. C. Schnabel.

(Berg- und Hüttenmännische Zeitung, 1898, p. 13.)

At Sondra, in the duchy of Saxe-Coburg-Gotha, a boring for potash salts was commenced, in 1895, in the Bunter sandstone, and reached the Zechstein dolomite at 120 metres. This was penetrated down to 196 metres, when the work was stopped owing to the constantly increasing discharge of carbon dioxide, which culminated in an explosion at the end of July, 1895, and the gas discharged freely into the atmosphere for a period of nine months, when the hole was plugged, and the gas brought under control, by lining the bore-hole with iron pipes, fitted with india-rubber at the top and provided with stop-valves. The pressure at the top was found to be 17 atmospheres in April, 1897; this was reduced to 11½ atmospheres when one of the valves, having an aperture of 1·8 inch, was opened. In the dry weather of October and November, 1897, the maximum pressure fell to 14½ atmospheres, but two days' rain sufficed to bring it back to 17 atmospheres. The yield of the spring, reduced to 10 atmospheres, is estimated at between 35,000 and 50,000 cubic feet per hour. The gas is entirely free from smell and taste, and contains 99 per cent. of carbon dioxide and 1 per cent. of nitrogen. The gas is carried by a wrought-iron pipe line, 2½ miles in length, to the works of the Sondra Carbonic Acid Company of Cologne at Settelstadt Station on the railway between Eisenach and Gotha, where it is freed from nitrogen by a method patented by Dr. Luhmann, which consists in dissolving the gas in water under pressure and forcing in pure carbon dioxide to displace the nitrogen, which becomes gaseous, and is allowed to escape. The dissolved carbon dioxide is then recovered by reducing the pressure, and the gas is liquefied by compression. Two compressors, each of the capacity of 3 cwt. of liquid acid per

hour, are in use, the motive power being supplied by a tandem compound engine of 275 and 400 millimetres (10·35 inches and 15·75 inches) cylinder diameter and 450 millimetres (17·75 inches) stroke, developing at 100 revolutions 85 to 90 HP. This is driven by carbon dioxide from the service main, the natural pressure being brought down to 10 atmospheres by a reducing valve, and giving 9 atmospheres in the slide-valve chest. The freezing of the exhaust is prevented by warming up the gas with a steam-heater at a cost of about 2*s.* 6*d.* per day for coal. From 250 to 300 steel bottles of 10 kilograms each are filled with the liquid acid in 10 hours, but the plant is now being increased to bring up the yield to 6 or 6½ tons, or 10 tons if the work is carried on continuously through the 24 hours. The electric lighting of the works is also to be effected by a carbonic-acid engine.

H. B.

On the Use of Pulsometers in a Zinc Mine. E. Frerichs.

(Zeitschrift des Vereines deutscher Ingenieure, 1898, p. 17.)

At the Samuelsglück zinc- and lead-ore mine near Beuthen, in Upper Silesia, the deposit, a nearly horizontal bed of dolomite containing blende galena and pyrites, was interrupted, at a point 500 yards from the main shaft, by a fault which was proved by boring to have a downthrow of 90 feet. As the depth from the surface (256 feet) was too great to bear the cost of an entirely new shaft the sinking to recover the deposit was started from the end of the main level, a distance of 662 yards from the bottom of the main shaft, a rise of about 23 feet being cut out to give room for the head-gear of the winding engine. This shaft, about 10 feet square, was kept dry by the kibble down to a depth of 40 feet, when, more power becoming necessary, it was decided to use a pulsometer, the steam being brought from the receiver of a pumping engine at the bottom of the main shaft by a covered pipe along the main roads of the existing workings. This has a total length of 820 yards, and is 4 inches in diameter, with copper expansion bends and steam drainers at intervals of 100 yards, the whole of the pipe as well as the receiver being covered with an insulating coating of infusorial earth. The pulsometer was mounted in a guide frame, and slung by a tackle from the pit frame like an ordinary sinking lift. It lifted 2 cubic metres (440 gallons) of water per minute from the bottom of the sinking down to 20 metres (65 feet) when it was drawn back and fixed at 15 metres, a second one being added as a sinking lift. The ore bed was cut at 23 metres and proved to be 4 metres thick, which, together with a sump of 3 metres, gave a total of 30 metres; the second pulsometer being lowered to the bottom to divide the lift. For drawing the ore from the bottom workings a double

8 × 10½-inch cylinder condensing engine, with cylindrical-geared drum and cages lifting 15 cwt. net load, has been provided taking steam from the same supply.

The pulsometers worked well, but the upper one required frequent cleaning owing to the deposit from the heated water from the bottom lift blocking up the holes in the diaphragm through which the condensing water is injected into the steam chambers and so stopping the working. As the stoppages were attended with the temporary drowning of the bottom level, and a second communication being necessary for ventilation and lowering timber, a new shaft has been sunk 40 yards distant from the first, in which two Rittinger pumps, driven by bell cranks from a condensing engine, have been erected. These have a total capacity of 4 cubic metres per minute, and have actually lifted 2·5 cubic metres (550 gallons) for the last six months. The steam is brought by an extension of the same line of pipes from the receiver supplying the winding engines. The ore lifted in 24 hours now amounts to 310 wagons of blende of 15 cwt. each—232 tons for 3,600 tons of water.

The cost of the machinery and steam-pipes for the new shaft was £928, divisible as follows:—

	£
Winding engines, head-gear, cages, &c.	215
Pulsometers, suspension frames, rising mains, and steam connections	328
Main steam-pipe, and coating expansion joints, water-traps, &c.	300
Erecting and small stores	85
	£928

This is considerably less than would have been required by any other method of transmission, and economy of fuel is a comparatively unimportant matter, the cost of dust coal of inferior quality as used at the mine being only 2*s.* 7*d.* per ton. Originally there were seven boilers of 750 square feet heating surface, six of which were generally in use, giving steam at 5½ atmospheres for the supply of the winding and pumping engines and the dressing machinery. When the new sinking was begun another boiler was added, and this has been sufficient to supply the additional steam. The loss of pressure in the ½ mile of underground steam-pipe was at first about 2 atmospheres, giving 3½ atmospheres at the receiver; but this has since improved, as notwithstanding the increased length of pipes the pressure available at the Rittinger pumping engine is 4¼ atmospheres.

H. B.

On the Occurrences of Ozokerite in Galicia. H. Arch.

(Allgemeine oesterreichische Chemiker- und Techniker-Zeitung, 1898, p. 5.)

Ozokerite or mineral wax occurs at numerous points on the northern flank of the Carpathians, the principal locality being Boryslaw, where twenty-eight out of the total number of forty-four mines at work are situated. These include 289 separate pits in addition to thirty-two in process of sinking, while 413 more are standing or abandoned. The depth of the workings has increased from a range of 24 to 176 metres in 1892 to between 74 and 214 metres in 1895. The output for 1896 is given as 7,210 metric tons, but this the Author considers to be too little, and that 830 wagons of 10 tons is a more likely quantity. As a rule, the mining appliances and machinery are of the most primitive kind, only one of the larger companies' mines being equipped with steam hoisting gear. The crude mineral is converted into kerosene by digestion with strong sulphuric acid at 200° C., and by fractional distillation into oils and paraffins of different classes, such as light burning oils at 150 degrees, and heavy oils between 150 and 200 degrees. Between 220 and 300 degrees a mixture of oil and paraffin is obtained that can be worked up either for the latter substance or for vaseline. The highest yield of paraffin is, however, obtained between 300 and 350 degrees. The residue, the so-called earth wax pitch, is not very unlike the crude mineral. The average proportion of these different constituents obtained on distillation are: light oil (benzene) 6 per cent., heavy oils 32 per cent., and paraffin 55 per cent., the remainder representing resinous and carbonaceous constituents and loss.

The Galician ozokerite differs from that obtained in the Caucasus, Moldavia, and North America by its low contents of resinous constituents, only about 2 to 3 instead of 30 per cent.

The value of ozokerite is about £30 per ton for standard up to £35 10*s*. for extra first-class quality. Second-class kinds fetch £22 to £27, and the so-called hard wax £35 10*s*. to £42. The total number of hands employed in the Boryslaw mines in 1896 was 500, from 12 to 15 per cent. of the number being women and children, the average wages paid being 2*s*. underground and 10*d*. to 1*s*. for surface hands.

H. B.

The Tropenas Steel-making Process.

(Engineering, 14 January, 1898, p. 43.)

This process is intended to enable iron-founders to make steel castings in an ordinary foundry. The Tropenas converter is similar to a small Bessemer converter, and contains about 10 cwts.

of molten metal. The bottom is made conical to give a large surface of bath. There are two rows of tuyeres, both being above the surface of the metal when the converter is vertical. Air at a pressure of 2 lbs. to 4 lbs. per square inch is blown through the bottom row, striking the surface of the metal at a slight angle with the horizontal, and causing it to be oxidized. The oxygen permeates the mass of metal by diffusion rather than by convection. Later in the process the converter is slightly tilted, so that the bottom row is submerged, and air is introduced through the top row. This completes the combustion of the hydrogen and carbonic oxide gases, which result from the oxidation of the metal by the air introduced through the bottom row, and a high temperature of bath results. The steel is very fluid, is free from cavities, and is quiet in the moulds. The metallic loss in the converter is about 14 per cent. A specimen 2 inches long, cut from a casting, gave 31·5 tons per square inch tensile strength, 34·5 per cent. elongation, and 54·3 per cent. reduction of area.

A. P. H.

The Manufacture of Oxygen Gas at Boulogne-sur-Seine.

P. Yvon.

(La Nature, 15 January, 1898, p. 103.)

After passing in review the various plans proposed for the preparation of pure oxygen gas for industrial purposes, the Author states that none have been found commercially practicable, with the exception of those in which the oxygen contained in the atmosphere has been made to combine chemically with some substance from which it may subsequently be readily dissociated. The processes of Mr. Boussingault and of Messrs. Tessié du Motay and Maréchal, both of them dating from the year 1884, are described, and the difficulties entailed in carrying them into practical execution are explained. The latter of these processes has been employed by Messrs. Dutremblay and Lugan for their works at Boulogne, built about two years ago. If a current of pure dry air is caused to pass over a mixture of soda and binoxide of manganese heated to about 450° C., the atmospheric oxygen is absorbed, giving rise to the formation of manganate of soda, and, if the temperature remains unchanged and a jet of superheated steam is substituted for the air-current, the mixture is regenerated into its original constituents, and oxygen gas is evolved. It is evident that in this reaction there is no theoretical loss of the chemical substances employed in the manufacture, and the immense advantage of this process is at once evident. By means of a series of illustrations, the various stages in the manufacture at Boulogne are described, concluding with the final storage of the

gas in steel cylinders, under a pressure of 120 atmospheres, in which it is sent out for commercial and scientific purposes. These works are capable of producing 3,500 cubic feet of oxygen gas per diem.

G. R. R.

Dustless Buildings. C. J. H. WOODBURY.

(Advance proof. Transactions of the American Society of Mechanical Engineers, November, 1897.)

In high American buildings, which give the tenants the advantage of quiet and light, excessive quantities of dust, blown in by the heating and ventilating apparatus, is often a serious difficulty. The Author was able to overcome this in the case of a building of 500,000 cubic feet capacity, through which 26,000 cubic feet per minute of air were usually blown. The outside air was drawn down a flue of 37 square feet cross-section at a velocity of 700 feet per minute, and was subsequently heated and finally delivered into each room. The method adopted by the Author was by placing filters in this flue, to mechanically intercept the dust. A timber frame was placed on the top, divided into square partitions. Under each was hung a cotton cloth bag 30 feet long, giving large filtering area, viz., twenty-seven times that of the original cross-section of the flue. Each bag was closed at the bottom, and was provided with an arrangement of ropes and pulleys to enable it to be raised and lowered. The particles of dust, striking the inner surface of the bags at an angle, glanced off and were carried to the bottom, instead of clogging the interstices of the filters. From half a peck to a peck per month of fine dust was collected from the bags, and the system was found to achieve its object perfectly.

A. P. H.

Statistics of the Growth of the Fleets of Various Powers.

(Mittheilungen aus dem Gebiete des Seewesens, 1898, p. 97.)

Particulars of the fleets of Austria and Hungary, Germany, England, France, Italy, and Russia, are given for the years 1866 to 1897 inclusive; first, by means of Tables showing the number of battleships, cruisers, torpedo-boats, destroyers, coast torpedo- and despatch-boats, their displacement, whether built of wood or iron, the number of guns carried (divided into three classes: heavy, medium, and light), the amount expended on new ships in any year, and the total cost of each service; second, by diagrams giving at a glance the tonnage of each class of ship possessed by the various powers in any year since 1866.

In 1897 the relative position of the nations concerned was as follows:—

State.	Battle-ships.		Cruisers.		Torpedo-Boats.		Destroyers.		Coast-Torpedo Boats.		Budget
	No.	Displacement.	No.	Displacement.	No.	Displacement.	No.	Displacement.	No.	Displacement.	
Austria-Hungary	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
Germany . . .	2·92	2·35	3·50	2·89	1·83	1·48	27·00	19·66	0·95	1·44	5·01
Italy	1·25	2·18	1·60	2·37	2·50	4·46	4·50	3·66	2·20	2·38	3·70
Russia . . .	3·42	3·08	4·50	5·29	1·33	1·42	7·50	6·66	2·01	1·54	8·11
France . . .	4·25	5·49	6·10	7·74	3·17	5·65	16·00	14·66	2·93	2·92	8·47
England . . .	6·42	9·31	13·40	32·45	5·17	10·20	42·50	69·33	2·28	1·51	19·14

W. B.

Recent Designs in Steamship Construction upon the Great Lakes.

RICHARD L. NEWMAN.

(Journal of the Association of Engineering Societies, 1898, p. 69.)

The Author contrasts the construction of some recent large cargo-carrying vessels with that of others built at an earlier period, and shows that by a proper disposition of the material of the hulls a very great improvement has been effected. He has constructed "equivalent girders" from the midship sections of several of the lake steamers, and shows that whereas in some of the earlier vessels the stress upon the material in the top of the girder, which is the upper deck, amounts to as much as 11·1 tons per square inch—a dangerously high figure—it has been reduced in modern examples to about 5½ tons, although the vessels are of greater length. This has been effected by putting less material in the bottom and more in the deck, and bringing the neutral axis more nearly to the middle of the section.

S. W. B.

Contract Trial of the United States Ship "Nashville."

W. STROTHER SMITH and C. B. PRICE, U.S.N.

(Journal of the American Society of Naval Engineers, August, 1897, p. 574.)

This steel twin-screw gunboat was built by the Newport News Shipbuilding Company from designs furnished by the Navy De-

partment; the price was £56,000 without armament. She is unprotected.

Length on water-line	221 feet 5 inches.
Beam	38 feet.
Depth	15 feet 11 inches.
Draught	11 feet.
Displacement	1,372 tons.

The armament consists of eight 4-inch quick-firing guns; six 4-pounders and four light guns. The guns on the upper deck are protected by shields, and those on the main deck by 2¼-inch sponson armour. The engines are quadruple expansion, having cylinders 11, 17, 24 and 34 inches diameter respectively, and the stroke is 18 inches. There are four water-tube boilers of the Yarrow type, fitted with Thornycroft feed-regulating gear. The total heating surface is 4,000 square feet, and the total grate surface is 100 square feet. There are in addition two marine boilers having a total surface of 1,350 square feet, and a total grate surface of 42 square feet. The power developed, using all boilers, was 2,536, and the speed 16·3 knots, giving an Admiralty coefficient value of 213. The steam-pressure was 252 lbs. and 154 lbs. in the Yarrow and Scotch boilers respectively, and the revolutions were 308 per minute. S. W. B.

The Contract Trials of the United States Gunboats "Vicksburg" and "Newport." H. N. Stevenson, U.S.N.

(Journal of the American Society of Naval Engineers, August, 1897, p. 549.)

These composite single-screw gunboats were built by the Bath Ironworks, Maine, from designs furnished by the Navy Department. They are steel-plated above and of wood below water. They are unprotected. The armament consists of six 4-inch guns, four 6-pounders and two light guns.

Length on water-line	168 feet.
Beam	36 feet.
Depth	22 feet 3 inches.
Draught	12 feet.
Displacement	1,010 tons.

The cylinders are 15¼, 23½, and 36 inches diameter respectively, and the stroke is 30 inches. There are two boilers of marine type, having a total heating surface of 2,524 square feet, and a total grate surface of 78 square feet. The power developed on trial was:—"Vicksburg," 1,118; "Newport," 1,009; and the speeds were 12·71 knots and 12·29 knots respectively, giving corresponding Admiralty coefficient values of 181 and 184. The steam-pressure was 185 lbs., and the revolutions per minute 146 and 143. S. W. B.

The Spanish Cruiser "Cristobal Colon."

(Engineering, 18 February, 1898, p. 206.)

This cruiser, which has been built by Messrs. Ansaldo & Co., of Sestri Ponente, is 328 feet long, 59 feet 9 inches in beam, and 23 feet 3 inches in draught, with a displacement of 6,840 tons. The propelling machinery consists of two sets of triple-expansion inverted engines, having cylinders 42 inches, 63 inches, and 93 inches in diameter, with a 46-inch stroke. The high-pressure cylinders are fitted with piston valves, and the intermediate and low-pressure cylinders, with double-ported slide-valves, all being worked with Stephenson's link motion. The condensers are of delta metal, and have a cooling surface of 14,600 square feet. The feed-tank is placed at a high enough level to give a constant head of water against the suction valves of the feed-pumps, which, as no air is drawn in, deliver almost the theoretical quantity of water due to each stroke. The boilers are twelve in number, of the Niclausse water-tube type. On the final trial, 10,671 I.HP. was developed with natural draught, and the mean speed was 19·35 knots. The armament consists of two 10-inch, ten 6-inch, six 4·8-inch, ten 2·25-inch, and ten 1·45-inch guns, all being quick-firing except the two 10-inch. This cruiser was very rapidly built, the interval from the laying of the keel to the full-power trial being only nineteen months.

A. P. H.

Value of Artillery Fire in Naval Battles.

Georg Ritter von Kirchmayr.

(Mittheilungen aus dem Gebiete des Seewesens, 1898, p. 1.)

The mode of fire in naval battles and the distances at which the various classes of ordnance should be brought into action are discussed.

Sighting instruments serve chiefly to eliminate errors due to motion of the target and firing platform and for approximate measurements of the distance separating them, for, in spite of improvements in the first, the influence the condition of the atmosphere has upon the explosives at present used, and its varying resistance to the flight of projectiles, remain governing factors which render trial shots necessary. It is pointed out that modern artillery uses up the available supply of ammunition so quickly that economy must be practised, and it is suggested that in gun-fire other than at point-blank range one unit should be employed until a hit is made, the remainder being trained on the target with the same adjustments and fired immediately that hit is seen.

Fire should be opened from each class of gun as that distance is reached when the object to be hit covers 50 per cent. of the probable vertical and horizontal deviation. The Author gives the effective range for modern heavy guns at 6,000 metres to 7,000 metres (3·7 miles to 4·4 miles), for guns of medium weight at 5,000 metres to 6,000 metres (3·1 miles to 3·7 miles), and for quick-firing guns at 2,000 metres (1·25 mile).

W. B.

Automatic Direction of Coast Guns. ADOLF LUDWIG.

(Mittheilungen über Gegenstände des Artillerie und Genie-Wesens, 1897, p. 903.)

After an introduction explaining the idea governing automatic direction, which consists in causing the act of sighting to give the correct elevation to a gun, the Author discusses the causes militating against accuracy of fire, and determines the limits within which the system may be advantageously employed.

The chief causes of inaccuracy are sighting errors and errors due to mechanical imperfections. As regards the first, the following approximate value is found—

$$\Delta x = \frac{x^2}{h} \Delta a,$$

when x = distance from the target;
h = height of gun above sea-level;
a = angle of line drawn from gun position to target with horizontal.

Assuming that a good eye can distinguish between two points when the apparent angle is greater than 50″, and setting $\frac{x}{100} = n$, the above equation becomes—

$$\text{for the naked eye, } \Delta x = \frac{2 \cdot 4}{h} n^2;$$

$$\text{with a telescope, } \Delta x = \frac{2 \cdot 4}{v\,h} n^2;$$

when v = magnifying power of instrument.

Having regard to the class of guns employed, and the ships they may attack, the effective striking zone, within the limits $x > 2{,}000 < 4{,}000$ metres (1·24 mile and 2·48 miles), and $h > 25 < 100$ metres (82 feet and 328 feet) is taken as 80 metres (262 feet) in length, whence

$$\Delta x = \frac{80}{2} = 40 \text{ metres};$$

and for the naked eye—

$$n_{max} = 4\sqrt{h}\,100 \text{ metres};$$

with a telescope—

$$n_{max} = 4\sqrt{v\,h}\,100 \text{ metres}.$$

On the basis of these formulas, the naked eye is sufficiently accurate for $h \gtreqless 100$ metres; for $h < 100$ metres a telescope is required, for which $v = 6$ is recommended.

In dealing with the question of mechanical accuracy, several systems are described and illustrated diagrammatically; in some the front sight is moved, in others the back, and in others both sights are moved in the same direction, but with different velocities. A proposal of the Author's is described at length, for which increased stability, sensitiveness, and accuracy are claimed, and in which—

(*a*) The movements of the sights are hydraulically controlled;

(*b*) The governing curve is not made in metal, but simply inscribed on a plate;

(*c*) A man is required to regulate the apparatus, so that a pointer always follows the governing curve.

If to attain accuracy mechanical considerations require a movement of the sight of at least 1 millimetre (0·039 inch) per 100 metres (328 feet) difference in range, then for the naked eye the sighting error governs the usefulness of the automatic apparatus; but when a telescope is used mechanical imperfection becomes the governing factor.

The article concludes with a discussion of the general influence of automatic direction of coast guns.

W. B.

The 40-*Inch Telescope of the Yerkes Observatory.* W. E. Reed.

(Journal of the Association of Engineering Societies, 1897, p. 125.)

The site chosen for the Observatory is on the edge of a prairie in the southern portion of Wisconsin, 75 miles north-west of Chicago, and is 1,200 feet above sea-level. The tower in the Observatory containing the large telescope is 92 feet in diameter and 52½ feet high, surmounted by a dome 90 feet in diameter supported on twenty-six wheels. The floor surrounding the central pillar, but clear of it, is 75 feet in diameter, and capable of rising and falling. Both floor and dome are moved by electric motors. The central pier has a massive base of concrete, and for 21 feet above this it is built of brickwork capped by a stone cope 15½ feet by 19½ feet and 18 inches thick. Upon this is carried the cast-iron column, 43½ feet high, which supports the telescope. The lens and its containing cell were prepared by Mr. A. G. Clark. The lens is composed of two single lenses of crown and

flint glass. The former is double convex 2½ inches thick at the centre and ¾ inch at the edge, and the latter is plano-convex 2 inches thick at the edge and 1½ inch thick at the centre. Both are 41½ inches in diameter, and their focal distance is 61 feet. The tube weighs 6 tons, and is built up of flanged steel tubes bolted together. Both polar and declination axes have roller bearings. The clock which rotates the telescope has a driving weight of 1½ ton. The tube can be moved on either axis and finally adjusted with tangent screws either by hand-gearing or through motors.

A. W. B.

Beraneck's Temperature Recorder.

(Gesundheits-Ingenieur, 31 December, 1897, p. 397.)

By reference to an illustration, an account is given of a recording apparatus, which was specially designed to indicate automatically the variations in temperature in the cold-storage chambers of the Vienna Market-hall. It was essential that the fluctuations in temperature should be confined within narrow limits, a range between a minimum of 2° C., and a maximum of 5° C. being demanded. The recording instrument is situated in the engine-house, and wires are brought from the two contact thermometers, placed in the storage chamber in a position where the temperature is fairly uniform, to the engine-room. A lithographed strip of ruled paper is wound round a brass drum, the large vertical divisions on the paper corresponding with the seven week days, and twelve smaller vertical divisions each representing two hours. This drum is made to revolve once a week at the necessary speed by clockwork. Two electro-magnets cause long levers, having at the extremities self-feeding pens, to be pressed against the paper on the drum, and lines are drawn by the upper one when the temperature on the index thermometer in the cold chamber rises above 5° C., and by the other, placed below it, when the second thermometer stands above 2° C. In order, therefore, to indicate the proper state of temperature in the chamber, only the lower line should appear on the diagram; this line ceases directly the index thermometer sinks below 2° C. The presence of two lines shows excess of temperature. The bulbs of the thermometer are plunged into vessels of oil, so as to avoid the recording of slight rapid changes of temperature due to draughts, or to the opening and shutting of doors, &c. The instrument has been in operation since April, 1897, and is stated to have worked satisfactorily.

G. R. R.

A New Harmonic Analyzer.

A. A. Michelson and S. W. Stratton.

(American Journal of Science, vol. v., 1898, p. 1.)

In that form of harmonic analyzer in which a flexible cord passes over a number of fixed and movable pulleys, the accumulated errors due to the stretching of the cord and its imperfect flexibility, neutralize the advantage gained by increasing the number of elements beyond a certain point. In the instrument invented by the Authors, this difficulty is overcome by the adoption of an entirely different principle, namely, the addition of the forces of spiral springs.

The first machine, constructed with twenty elements, was so successful that it was decided to apply to the Bache Fund for assistance in building the present machine of eighty elements, the general arrangement of which is shown in perspective elevation in a figure.

A long horizontal cylinder, turning on knife-edged pivots at each end, has attached to its circumference a row of eighty small spiral springs. The action of these springs is resisted by one large counter-spring fastened to the back of the cylinder. Each of the small springs is carried by a lever to which is given a harmonic motion by means of an eccentric. The amplitude of the motion can be regulated by adjusting the position of the connecting-links, and the phase can be altered by disengaging it from the driving gear, which is so arranged that the eccentrics have periods increasing in regular succession from one to eighty.

Under the combined action of the small springs, resisted by the constant pull of the large spring, the cylinder is caused to oscillate, and the resultant motion is recorded by a pen connected with a lever rigidly attached to the cylinder.

The efficiency of the machine is illustrated in the summation of Fourier series, shown in the accompanying Figs., some of which represent standard forms, while others are curves, which it would be extremely difficult to construct by any other means.

The machine can also perform the inverse process of finding for any given function the coefficients of the corresponding Fourier series. Of this several examples are given, the average error being about 0·7 per cent. of the value of the greatest term.

The complete cycle of operations of finding the coefficients of the complete Fourier series (sine and cosines) and their recombination, reproducing the original functions, is strikingly illustrated by the last Fig. The curve chosen represents the profile of a human face. This is analyzed and its coefficients determined, and finally the curve is reconstructed by the machine with sufficient accuracy to be plainly recognizable.

G. J. B.

A Coal-Gas Electric Cell. Dr. Borchers.

(Elektrotechnische Zeitschrift, 1897, p. 692. 14 Figs.)

The Author first refers to his experimental work in 1894 upon the use of a solution of copper chloride, on the one hand, for the solution of carbonic oxide and other gases obtainable from coal, and on the other hand for the solution of oxygen, so that with suitable electrodes it might be possible to produce an electric cell with carbonic oxide, copper chloride, and oxygen. The electrodes were copper and carbon, and the Author thought it possible to construct the cell itself of copper. The first apparatus of 1894 consisted of a glass vessel with two glass partitions which did not quite reach the bottom. Each of the outer divisions contained a copper tube with inlet for gas, the central division a tube of carbon open to the air. This was changed later on by shortening the copper tubes and fixing to them perforated copper plates supporting granulated copper to get more surface, and still later a copper vessel was used containing the copper chloride solution of carbonic oxide while a porous pot with copper chloride was used as the air vessel. The first apparatus consisted in principle of three liquid columns connected at the bottom. The copper chloride was at the bottom, oxygen at the top of the central column, and carbonic oxide at the top of both the others. All the persons who repeated the experiments of the Author attempted to use a porous cell to separate the carbonic oxide and oxygen, but Prof. Haüssermann had proved this impossible. The Author then describes an improved form of cell giving better control of the gases by means similar to those used in gas-meters. A special form consisting of a U tube is shown, each leg being provided with an open platinum tube sunk vertically to half its depth in the liquid. Circulation is promoted by sending a jet of air down a small tube in the centre of the platinum tube. The Author has used a gelatinous electrolyte; instead of this he might use mercury. He describes his latest apparatus as consisting of an iron or lead box containing Weldon mud. A porous vessel is dropped into the box, and contains a solution of copper chloride. A carbon plate forms the electrode, and gas is let into the porous cell and air into the metal vessel. The electromotive force obtained varied between 0·07 volt and 0·61 volt, according to the resistance in the external circuit. Results of tests with chloride of tin, manganese chloride, manganese sulphate, and ferric sulphate are given. Further experiments on the cell have been undertaken by Prof. Nernst, of Göttingen, and in the laboratory of the Elberfeld Colour Works.

E. R. D.

Testing Three-Phase Induction Motors. W. T. Morrison.

(The Electrical Engineer, New York, vol. xxiv., 1897, pp. 453 and 476.)

In these two articles, the Author gives some practical hints on the testing of three-phase induction motors and outlines various methods of localising faults in them. He also gives diagrams of the transformer connections used for three-phase work. The details apply essentially to machinery of the General Electric Company's design. Approximate values of the current which different sized motors should require at full load in each phase are given, and the Author states that the maximum output of these motors is usually 150 per cent. of the rated power. Special motors for elevator work or driving coal-cutting machinery have a higher maximum output before breaking out of step. The best methods of localising a reversed or broken connection in one of the windings are detailed fully, and a Table is given from actual tests showing the results of such faults. From this Table the effect of the faults in the current and speed of the motor are readily seen.

The articles are illustrated by diagrams of connections.

R. W. W.

A New Arrangement of the Joubert Phase Indicator.

Wilhelm Kübler.

(Elektrotechnische Zeitschrift, 1897, p. 652. 3 Figs.)

So much has been written upon the various forms of the Joubert mechanism for observing the periodicity of alternating currents that it might be thought the apparatus was now perfected, but the Author has found great difficulties in practical use. In the use of the disk and moving contact in the workshops the sparking is so great at high potentials that it becomes practically impossible to obtain a satisfactory curve. This could be obviated by the use of static instruments if it were possible to obtain them of great sensitiveness for high potentials and at the same time not easily deranged by rough usage. He considers that all difficulties may be overcome by using an ordinary instrument which is short-circuited by means of conductors ending in two brushes pressing upon a metal cylinder which is caused to revolve synchronously with the alternator. The instrument is connected across the leads from the alternator, a suitable resistance being inserted, and the metal cylinder has in one place a groove which causes the short circuit of the instrument to be opened momentarily, and the needle then gives a reading; no sparking occurs at the brush contacts. This arrangement has been satisfactorily in use in the laboratory of Messrs. Ludw. Loewe & Co. for some time.

E. R. D.

A New High-Tension Electric Transformer.

O. DE ROCHEFORT-LUCAY.

(Bulletin de la Société des Ingénieurs Civils de France, 1897, p. 217.)

The Author, in conjunction with Mr. Wydts, has devised a transformer in which the difficulty of insulation is overcome by the use of a viscous material, generally one of the carburets of hydrogen. The transformer as constructed and described gives a spark 20 to 22 centimetres (7·87 to 8·66 inches) in length with 6 volts and 3·3 amperes, *i.e.*, about 20 watts. To obtain the same result with a Ruhmkorff coil, the number of watts required would be 120, and the weight of the induction coil about 5 to 6 kilograms (11 to 13·25 lbs.).

The new apparatus, having an induction with a weak resistance, gives, with equal tensions, a yield greater in intensity than a corresponding Ruhmkorff coil. It is therefore better suited for the production of X rays, as, under the same tension, their emission increases with the amperage of the secondary current.

H. I. J.

The Determination of Hysteresis Loss.

H. F. PARSHALL and H. M. HOBART.

(Engineering, 14 January, 1898, p. 41.)

In the old step-by-step method, the sample, which is made ring-shaped, is surrounded by the primary coil, of which the magnetomotive force is gradually varied. From the corresponding deflections of a ballistic galvanometer through a complete cycle, the ordinary hysteresis curve is plotted, of which the area represents the hysteresis loss in ergs per cubic centimetre, or watts per lb. of material per cycle per second. The Holden hysteresis tester measures the loss in ring-shaped samples of sheet iron when placed between the poles of a rotating magnet. Surrounding the rings is a coil of insulated wire. The alternating current induced in this is rectified and measured by a voltmeter, the reading of which corresponds with the induction. The torque tending to rotate the rings is resisted by a spiral spring, of which the angular deflection represents the loss per cycle. In the Ewing hysteresis tester, the test sample is rotated between the poles of a permanent magnet mounted on knife-edges, and carrying a pointer which moves over a scale, being kept in the central position by a weight. The deflection of the permanent magnet corresponds to the hysteresis loss of the sample, and is found to be independent of the thickness of the latter, so that no correction for such variation is necessary.

A. P. H.

Transport and Distribution of Electrical Energy.

G. DUMONT and G. BAIGNÈRES.

(Memoires de la Société des Ingénieurs Civils de France, October, 1897, p. 437.)

The production of electrical energy from natural sources of power, and its distribution to places at a distance, having attained considerable dimensions in France and Switzerland, the Authors consider it of interest to investigate:—

(1) The different systems of transport of electrical energy.

(2) The conditions governing the establishment of transport lines.

(3) The development caused by the transport of power in France and Switzerland.

(4) The most typical examples of transport carried out, and the cost at which energy can be supplied.

The first portion of this Paper is devoted to descriptions of the various systems for the carrying of the current, their advantages and disadvantages; the details of arrangements of the generating stations and motors, and the arrangements necessary for transforming the current for lighting and power purposes.

A description is then given of tests carried out at the River Reuse by a jury of specialists, to determine the most economical of three systems of transport:—

(1) Alternate current monophase.

(2) Alternate current triphase.

(3) Continuous current at a constant pressure—from the results of which a unanimous decision was given in favour of continuous currents.

The details of the fixing of the mains for high-tension currents occupies the next section, and a description is given of work carried out on the Goule, and also at Olten-Aarburg, Wohlen, and Zurich.

The development caused by the establishment of generating-stations at the waterfalls of France and Switzerland is then described, and the average cost given of current supplied. For power purposes this varies from 10·5 centimes (1·05*d.*) for small powers, to 6·3 centimes (0·63*d.*) for large powers, per HP.-hour. For lighting purposes the price per hectowatt-hour varies from 0·08 franc to 0·067 franc (0·77*d.* to 0·66*d.*).

In concluding, the Authors give notes upon various existing installations, those selected being the Val de Travers, La Chaux-de-Fonds, St. Imier on the Goule, Olten-Aarburg, and La Société Lyonnaise on the Rhone.

The Paper is illustrated with thirteen Figs. and four maps.

H. I. J.

The Synchronograph. A. C. Crehore and G. O. Squier.

(Transactions of the American Institute of Electrical Engineers, 1897, p. 123.)

The device brought forward in this Paper by the Authors (who are its inventors) has for its main object the acceleration of telegraph despatching by means of the employment of alternating currents comparatively large in regard to magnitude and electromotive force.

The variations in current strength which constitute or give rise to the signals forming messages, are caused by making or breaking the circuit at the instant that the alternating wave passes through a zero point; there is, therefore, no spark and no alteration or disturbance of the regular wave-form which would follow if the circuit were opened or closed at an instant when the current wave had an ascending or descending form.

The mechanical contrivances for thus operating a switch synchronously with the current wave are described and illustrated; and in addition to such transmitting appliances, the Authors enter very largely upon the corresponding mechanism of "receivers," either the photographic or the chemical form being preferred. For transmission it is necessary first to prepare tape somewhat in the usual way, by punching with dots and dashes; with such a combination it is stated that messages have been sent at the rate of about 1,200 words a minute for actual transmission.

The Paper was discussed by the members of the Institute on two occasions; and the general tone of the remarks made appears to have been in the direction of highly appreciating the great ingenuity of the appliance, and of doubt as to whether the additional cost of installation and working of such an entirely new system would outweigh its decided advantages from an engineering standpoint.

F. B. L.

Note on the Electrical Properties of Underground Cables.

P. Heina.

(Annales Telegraphiques, 1897, pp. 445–478. 11 Figs.)

The results given in this Paper were obtained by tests made in November and December, 1896, upon the underground cable connecting Marseilles and Toulon. The cable consisted of six pairs of conductors each formed of a single copper wire 0·078 inch in diameter. The conductors were insulated with two layers of paper. The two conductors of any given pair were twisted in a spiral having a pitch of about 1 yard, and are distinguished by a thread of a particular colour. The whole is covered with lead 0·138 inch thick.

The Author proceeds to describe in detail the tests made for resistance, capacity and self-induction. With respect to the insulation resistance it was stipulated in the specification that each conductor was to be tested with a battery of at least 100 volts potential with all the other conductors connected to earth. This method, however, was found to be impracticable owing to the disturbance produced by the electric tramway at Marseilles. Curves are given showing the variation in potential of the earth at Marseilles. The total length of the cable tested was 40 miles, and the insulation resistance was found to average 4,392 megohms per mile. Telegraphic tests were then made with Hughes and also with Baudot instruments upon a single wire, while the results of induction upon each of the remaining eleven were recorded. A comparison was then made between the results obtained on the underground cable with results obtained under similar conditions on the overhead telegraph wires between Marseilles and Toulon. Tests of the conductors used for telephonic work were then made, and the results are given in the form of tables. In comparing the speaking power on the overhead and underground lines it was found that they were in the ratio of 19 : 15, and it was possible to make speaking equally audible by talking at a distance of 8 inches from the microphone in the case of the underground line, and at a distance of 27 inches in the case of the overhead line.

E. R. D.

Photometric Measurements of Alternate Arc-Lamps.

W. Wedding.

(Elektrotechnische Zeitschrift, 1897, p. 716.)

The statements as to the candle-power of alternate-current arc-lamps differ so greatly that it is scarcely possible to compare the light of the direct and alternate-current arcs. The Author believes that the following experiments carried out at the Royal Technical High School in Berlin will help to fill the gaps.

These experiments were grouped under four headings: (1) influence of the reflector; (2) influence of the diameter of the carbons; (3) dependence of the candle-power on the current and energy; (4) comparison between alternate and direct-current arc-lamp candle-power.

The particular lamp tested was by Messrs. Körting & Mathiesen, and details are given by the Author. As the candle-power of the lamps depends upon the form of the current curve, which should approach a sine form as closely as possible, an eight-pole three-phase machine was selected with a frequency of fifty. The photometric measurements were taken below the horizontal at two points diametrically opposite by means of an angle photometer.

The effect of position of reflector was first tested with an enamelled iron reflector 47 inches diameter, and the general result was that the reflector only increased the illumination about 50 per cent. instead of doubling it. The Author then explains how he obtained the best position of the reflector by noticing the shadow thrown on it by the edge of the upper carbon. Reflectors of 47 inches diameter and 59 inches diameter were tried, and the results found scarcely different. Tests with various diameters of carbons were next made, all the carbons being made by Messrs. Siemens & Co., of Charlottenburg. It was proved that with carbons of 10 millimetres and 12 millimetres respectively about 18 per cent. more watts were expended in the larger one with the same current and less candle-power obtained. Dependence of the candle-power on the current and energy: during the tests the phase curves were also obtained, and the currents varied from 4 amperes to 40 amperes. The results are all detailed in Tables, and it appears that the watts per Hefner standard candle were 4·42 for a current of 4·02 amperes, and diminished rapidly up to 9·3 amperes, where a candle-power is obtained for 0·988 watts, and then gradually to 40 amperes, when that candle-power is obtained for 0·688 watts. The Author finally compares the light given by direct and alternate-current lamps, and shows how much more efficient the former are than the latter, but points out that it is possible to obtain in some cases better distribution of light, as three alternating arcs can be used in series on 110 volts, whereas only two direct ones can be so employed.

E. R. D.

A New Method of Fixing Arc-Lamps. H. Rentzsch.

(Elektrotechnische Zeitschrift, 1897, p. 419. 5 Figs.)

The Author points out that the usual method of using arc-lamps in high positions necessitates an ugly bight of slack cable; this may be got over by bringing the leads to a socket with contacts at the place where the lamp is to be placed and providing a plug upon the upper part of the lamp itself. Raising and lowering of the lamp is effected by means of a small crab and wire rope; the objections to the last method are that the socket is often fixed in a place difficult of access, and there is no current flowing to the lamp while it is in its lower position. The Author has produced a type of raising and lowering gear in which the rope or cable supporting the lamp is also the conductor.

The ordinary leads are brought up to two terminals upon a case suitable for fixing against a wall and containing a winding drum with a pair of contact rings upon an inner spindle insulated from the framework. Upon the said rings brushes are held in contact by springs and the current is delivered to a specially made cable

containing copper wires for the conductors and steel wires to carry the load. The cable passes over suitable grooved pulleys and supports the arc-lamp. The drum is provided with a pawl in the usual way.

E. R. D.

Private Branch Telephone Exchanges.

(The Electrical Engineer, New York, vol. xxiv., 1897, p. 497.)

This is a description of a comparatively new departure made by the New York Telephone Company. In large commercial works and also in newspaper offices and steamship companies a private branch telephone exchange is established. The various departments of the business are connected to this exchange, and private wires are also run from it to certain places with which special facilities are wanted. A certain number of trunk wires connect this branch exchange to the main exchange of the telephone company.

Under the previous arrangements these trunk lines were connected to different departments under a distinctive number on the company's list of subscribers. With the present arrangements a single number only is required and the departmental switching is done at the branch exchange. This exchange is also used for the private business between the departments. It is claimed that these arrangements greatly facilitate communication and that the irritating reply that a certain line is engaged is generally avoided. Illustrations of the system are given and also the rates charged per annum by the telephone company.

R. W. W.

On the Working of Discontinuous Lightning Conductors.[1]

K. R. Koch.

(Elektrotechnische Zeitschrift, 1897, p. 639.)

In the present Paper some further results are given dealing with the variation in resistance of discontinuous conductors during thunderstorms. Prior to the storm of 5th June, 1897, the resistance of the conductor tested varied from 300,000 ohms to infinity, but during the storm it was much diminished, the change taking place at the moment of the lightning-flash. In one case it fell to 190 ohms; again, on 30th June, it fell momentarily to 230 ohms. As the throw of the galvanometer is diminished during a storm, it is somewhat difficult to observe with absolute accuracy, but the Author believes that each flash

[1] Minutes of Proceedings Inst. C.E., vol. cxxx. p. 232.

is accompanied by a sudden diminution in the resistance of the lightning-conductor. He discusses the causes of the effect, and observes that an electroscope showed no deviation, so that probably the effect is produced by electric oscillations. He alludes further to a proposal first brought forward by him in 1893, and founded on Maxwell's idea for the protection of whole groups of buildings. It would suffice to run wires from house to house, and to carry down, say, at each house a wire to earth connecting up to the metallic masses such as rain-water pipes, &c. Where a three-wire electric system is in use the bare middle wire might be employed as the lightning-protector by carrying it over the roofs. He recommends that this point should not be lost sight of in future rules relating to lightning-protectors.

E. R. D.

Compressibility of Gases. A. Leduc.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxv., 1897, p. 646.)

This Paper is a continuation of a former one (see Phys. Soc. Abstracts, No. 603, Oct. 1897; C. R., 125, pp. 297–299, 1897). The present communication contains a much fuller Table than the last, giving values of certain constants for a large number of gases, the constants not having a direct physical meaning in themselves, but being connected with the equations for the compressibility given in the former Paper. The Author has found a connection between these constants and some of the physical properties of the gases.

J. B. H.

Expansion of Gases. A. Leduc.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxv., 1897, p. 768.)

From the results of a former experiment by the Author on the density of one of the gases at 0° and 760 millimetres and his experiments on the compressibilities of a number of gases at 16°, he has calculated their coefficients of expansion. The results are given in tabular form and agree remarkably with those obtained by experiment.

It is impossible to give here any idea of the methods of calculation, as this Paper, together with the other by the same Author abstracted above, and a third referred to, form in reality one investigation, the equations of the first Paper being used in the others.

J. B. H.

Dielectric Strength of Oils. E. F. Northrup and G. W. Pierce.

(Electrical World, New York, vol. xxx., 1897, p. 559.)

The oils under test are subjected to pressures from a high-frequency coil, a transformer, and an induction-coil. The high-frequency coil was capable of giving a smooth continuous discharge through 10 inches of air; the induction-coil gave a heavy 4-inch spark, and the same coil used as a transformer with 100 volts on the primary discharged through about ½ inch of air. In the following Table, which is a brief summary of the results, the numbers give the maximum and minimum ratios of oil-strength to air-strength through the range tested:—

Kind of Oil.	High-Frequency Coil.	Transformer.	Induction-Coil.
Transit	14·0—24·8	7·8— 0·9	3·9— 9·7
Engine	29·1—37·2	5·8— 0·99	3·9—16·0
Kerosene	47·6—67·5	21·0—26·6	10·3—35·0

These results show that kerosene is the best insulator.

W. G. R.

Dielectric Strength of Oils. C. P. Steinmetz.

(Electrical World, New York, vol. xxx., 1897, p. 609.)

The Author quotes some results given in a Paper by Messrs. Northrup and Pierce in the *Electrical World* of November 6th, viz.:—

First.—The ratio of oil-strength to air-strength depends upon the source of power, being lowest under the strength of alternating currents, highest with oscillating currents of a high frequency, and intermediate with the current of an induction-coil.

Second.—The ratio of oil-strength to air-strength increases with the striking distance; that is, the voltage, except with heavy oils and alternating currents.

Third.—In the latter case the strength of oils falls to, or even below, that of air at high voltages.

He does not think that the shape of the wave is the cause of these differences, but rather the powerfulness of the source of supply. He also remarks that in his opinion dry oils have a dielectric strength far superior to that of air at high voltages with alternating currents.

W. G. R.

Insulating-Materials. F. W. Phisterer.

(Electrical World, New York, vol. xxx., 1897, p. 554 *et seq.*)

The requirements of a good insulating substance are that it should be waterproof, fireproof, tough, flexible; it should possess the power of closing again any cracks which may occur in it from any cause, and it should be easy of application and cheap to manufacture, as well as being a good insulator.

The Author considers many insulating substances, such as sulphur, silex, various asphalts, pitches, mineral wax, sapho, ozite, and paraffin wax, and gives a very complete account of what is known of their various physical qualities. Mixtures of these substances are also dealt with, and an amount of information on the subject is given which is not obtainable elsewhere in a collected form.

W. G. R.

The Resistivity of Reostene. E. Van Aubel.

(Journal de Physique, 1897, p. 529.)

This alloy, a nickel-steel, due to W. T. Glover, Salford, brazes easily and can be soldered with ordinary solder. Its density is 7·8991. The resistivity at 0·44° is 77·07 microhm-centimetres, with a coefficient of variation of 0·00119 between 0·44° and 14·47°, of 0·00116 between 15·6° and 57°, of 0·00114 at 74·1° and of 0·00098 between 74·1° and 100·5°. The resistivity is thus very high and the coefficient of variation is fairly constant between 0° and 74° C., a property which other alloys do not possess. When this alloy is cooled to 0° C., after being heated it regains its original resistivity completely.

A. D.

Magnetic Screening. J. A. Erskine.

(Annalen der Physik und Chemie, vol. lxii., 1897, p. 145.)

A glass-hard steel needle, when magnetized, is a good test for rapid electric oscillations; they act like percussion and partly demagnetise it. The Author utilizes this property for measuring the screening action of metallic cylinders against the influence of a rapidly varying magnetic field, produced by the discharge of a Leyden jar fed by an influence-machine. He introduces coils of various sizes into the circuit of the condenser, and determines the demagnetizing effect of each coil upon the same steel needle magnetized to saturation. He then surrounds the needle by a screen in the shape of a glass tube covered with tinfoil, and

discharges through a stronger coil so as to obtain the same demagnetizing effect as before. One of the most interesting results obtained is that the screening action is almost annulled by slitting the metallic covering lengthwise. The screening action increases with the diameter and with the thickness of the tinfoil tube. The relation with the thickness is complicated, and is only approximately represented by the formula H $(1 - e^{x})$, where H is the field and x the thickness. The screening action is greatest when the first half-oscillation acts in favour of the existing magnetization. Most of these peculiarities are easily explained by the ordinary theory of induction, regarding the tinfoil as a secondary circuit in which the induced currents tend to neutralise the variations of the field. As regards, for instance, the influence of the diameter, it must be remembered that an increase of diameter means an increase of resistance, self and mutual induction, and also an increased difference of phase.

E. E. F.

Liquefaction of Fluorine. H. Moissan and J. Dewar.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxv., 1897, p. 505.)

The boiling-point of fluorine is very near to −187° C. At −210° it is still very mobile. An interesting accident, by which air entered and was instantly liquefied, produced two layers in the tube—the upper, colourless, of liquid air; the lower, of a pale yellow, being fluorine.

Physical Properties.—Substances of known density were immersed in the liquid, it being first ascertained that at that temperature (−200°) they were not attacked, if they had been previously sufficiently cooled. In one case, when this precaution had been neglected, a fragment of caoutchouc took fire on the surface of the liquid, and burnt with intense brilliancy without any deposit of carbon. It was found that wood, caoutchouc and ebonite floated on the liquid, methyl oxalate sank, while amber remained suspended and became almost invisible; hence the specific gravity of liquid fluorine may be taken as 1·14, and its refractive index about the same as amber. Its diminution of volume from −187° to −210° was $\frac{1}{14}$. In this experiment, through the accidental exhaustion of the liquid air, a violent explosion occurred, and the apparatus was reduced to powder.

Its absorption-bands could be observed in any of the specimens in a layer of 1 centimetre. The liquid was not magnetic. The capillarity is low, capillary tubes plunged into different liquids giving a height in millimetres of:—fluorine, 3·5; oxygen, 5·0; alcohol, 14·0; water, 22·0.

Action on Various Substances.—Hydrogen instantly combines with fluorine even at −210°, with great heat and light. Oil of

turpentine explodes with a deposit of carbon. As a striking proof of the intense activity of fluorine, when, on several occasions, a little of the liquid was dropped on the floor the wood caught fire.

Oxygen.—The detonating body mentioned in the previous Paper was further studied. The conclusion is that this body, which is only formed in the presence of moisture, is an unstable hydrate of fluorine, although it was found that liquid fluorine did not react on water until the initial temperature of $-210°$ was raised, when an energetic action ensued under strong formation of ozone.

Mercury was not attacked at the low temperature.

Conclusions.—Fluorine is liquefied with facility at the temperature of ebullition of liquid air. Its boiling-point is near $-187°$. It is soluble in all proportions in liquid oxygen or air. It does not solidify at $-210°$. The other conclusions are embodied in the abstract.

S. G. R.

Densities of Liquefied Gases. A. Leduc.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxv., 1897, p. 571.)

New experiments give the following densities:—

CO_2	1·5287	Cl	2·4907
N_2O	1·5301	NH_3	0·5271
HCl	1·2692	SO_2	2·2639
H_2S	1·1895		

Slight details of the modes of preparation, etc., are given.

R. E. B.

Molecular Volumes and Densities of Gases. A. Leduc.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxv., 1897, p. 703.)

By means of the constants referred to in the abstract of the Paper on "Compressibility of Gases" the Author has determined the molecular volumes at 0° and the densities at 0° of the gases for which the constants were determined. These he has given in tabular form in the Paper.

J. B. H.

Preparation of Percarbonate of Potash. P. T. MÜLLER.

(L'Éclairage Électrique, 1897, p. 107.)

Theory of Reaction.—If a solution of carbonate of potash, K_2CO_3, be electrolysed, it may be admitted, according to the theory of electrolytic dissociation, that ionization takes place according to the form K/KCO_3. The anion formed by the radicle KCO_3 is directed towards the anode, and there, if suitable conditions exist, two of these radicles may combine to form the molecule $KCO_2 - CO_2K = K_2C_2O_6$.

Preparation of the Salt.—Electrolysis takes place in two cylindrical vessels surrounded by a freezing mixture. The central vessel is porous, and contains the kathode and a dilute solution of carbonate. The external vessel contains the anode, which is of platinum (iron, nickel, copper or silver would be rapidly attacked). During the process of electrolysis a concentrated solution of carbonate of potassium is introduced into the lower part of the anode chamber by means of a funnel and tube; the percarbonate liquor which is formed (and in which the greater part of the new salt is found in suspension) is lighter than the solution of carbonate, and can be collected drop by drop. This is then filtered by suction, and a moist product is obtained containing 87 per cent. to 93 per cent. of percarbonate. The output is 2·2 grams to 2·4 grams of solid salt per ampere-hour. (The theoretical output, assuming no losses due to dissolution and decomposition, would amount to 3·6 grams.) This product is then spread out on plates of porous porcelain and dried in a current of hot air. After 12 hours' desiccation the substance contained scarcely more than 6 per cent. to 8 per cent. of moisture. Towards the end of the operation the air-temperature may be increased to 40°. A higher temperature than this gradually decomposes the salt.

The Author then deals with the conditions of preparation:—If at the commencement of electrolysis the temperature is $-15°$ and the density of the anode liquid high, then small variations of temperature produce little effect. With a decrease in the strength of the carbonate the output decreases with an increase of temperature. The concentration of the anode liquid should be as high as possible. The output is also increased by a high current-density.

Percarbonate of potassium when dry is a slightly blue amorphous powder, of a very hygroscopic nature; when damp the salt becomes bluer, and gradually loses its oxygen. This salt is useful for the preparation of oxygen. When placed in water at a temperature of 45° a regular supply of gas is obtained without any application of heat, and to avoid a simultaneous discharge of CO_2 a little soda is added. Owing to its powerful oxidizing properties the Author considers that this salt should be of industrial use.

Mr. A. von Hansen has not yet succeeded in preparing the salts of sodium and ammonium. The manufacture of percarbonate of

potassium has been patented under the title "The Process of Electrolytically Preparing the Salts of Percarbonic Acid" by E. J. Constam, A. von Hansen, and "Aluminium-Industrie Actien Gesellschaft," German Patent No. 91,612.

L. J. S.

Electrically-operated Electric Engine-Room Telegraph.

C. Arldt.

(Elektrotechnische Zeitschrift, 1897, p. 487.)

This apparatus, which was originally designed by Dr. L. Weber, of Kiel, and is constructed by the Allgemeine Elektricitäts-Gesellschaft, comprises a switching device whereby a magnetic field in the receiver turns synchronously with the lever of the transmitter, so as to produce a perfect rotary field. In this rotary field-indicator, the transmitter consists of an annular resistance-coil closed on itself and divided into sections, each of which is connected to a bar of a circular commutator, over which moves a lever having a sliding contact-piece at each end. These sliding contacts are adapted to engage with diametrically opposite bars of the commutator, and are each connected, through sliding-brushes and fixed contact rings, with terminals to which current is supplied from any suitable source. To three of the commutator-bars, at 120° apart (for which purpose the number of bars must be divisible by three), are connected conductors leading the current to the receiver. This receiver consists of a system of three (or a multiple of three) similar magnet-coils arranged with their axes at 120° apart around a pivoted arbour which carries a magnet and a pointer moving over a suitably-marked scale. The inner ends of these coils are connected together, whilst their outer ends are each connected to one of the conductors from the transmitter.

Assuming now, for illustration, that the transmitter and receiver are arranged so that the axes of the magnet-coils in the receiver are parallel to radii joining the centre of the commutator to the points of connection of the three conductors, and the lever carrying the contacts is placed with one contact over one of these points of connection, and the other contact midway between the other two of these points. When this is so, it is obvious that the inner pole of the magnet corresponding to the point of connection on which the sliding-contact rests, will be, say, of S polarity, whilst the inner poles of the other two magnets will be of N polarity, and consequently the N-pole of the magnet on the pivoted arbour will be attracted towards the magnet-coil whose inner end is of S polarity, whilst its S-pole will lie midway between the other magnets whose inner ends are of N polarity. It follows that the pointer will turn through 180° when the contact-arm is turned through a like angle, and that the results

will be similar in whichever of the three main positions the contact-arm is placed, and that the contact-arm and pointer will also remain parallel to each other for intermediate positions, since the currents along the three conductors and magnet-coils will vary regularly approximately according to a sine law, there being a difference of phase between them of 120°. The number of signals transmitted may be very large; for example, it is possible to so arrange the apparatus that it will indicate accurately from degree to degree, so that 360 separate signals can be transmitted.

When used for an engine-room telegraph, each transmitter is preferably combined with a receiver, so that when the indicator-arm on the bridge has been set to any position, the order can be acknowledged by the engineer in the engine-room by setting his transmitter to the same position; thus both the arm of the transmitter and the pointer of the receiver on the bridge will be on the same division of the dial. A bell can be rung automatically when the indicator-arms are moved.

When used as a water-level indicator, the contact-arm in the transmitter can be mounted on a spindle bearing a sprocket-wheel over which passes a chain connected to a float. The indicator can also be employed for a number of other purposes.

C. K. F.

Automatic Regulator for Dynamos. F. Collischonn.

(Elektrotechnische Zeitschrift, 1897, p. 357.)

The Author first gives a short sketch of the various types of automatic regulator already designed, and then proceeds to describe his own. The principle of this regulator is as follows:—In parallel with the dynamo are arranged two electro-magnets which are each provided with an armature adapted to be pulled away therefrom by a spiral spring. The pull of these spiral springs is so adjusted that, when the P.D. between the terminals of the dynamo is normal, one of the armatures will be held away from its magnet, whilst—likewise at the normal P.D.—the second armature will not be pulled away from its magnet by the spring. From this it is obvious that the first electro-magnet only acts when P.D.'s occur which are higher than the normal, whilst the second is only influenced by those which are below the normal. The circuit of the first electro-magnet is provided with an interruptor in a similar manner to the electro-magnet of an electric bell, so that, when the current in its coils reaches a certain value, the armature will begin to vibrate, this action continuing until the P.D. falls to the normal. To produce vibration of the armature of the second electro-magnet, when the P.D. falls below the normal, its circuit is permanently connected across the dynamo terminals, and an auxiliary circuit, in parallel with the other and containing the

interruptor, is provided for producing the vibration. This vibratory motion of the armatures is utilized to rotate a metal ring turning on a series of rollers, in one or the other direction accordingly as one or the other armature is vibrating, this being effected by providing suitably-arranged pawls on the ends of the said armatures for engaging with a series of teeth formed on the periphery of the said ring. This ring is provided with a series of iron pins, mounted in, but insulated from, the ring and connected to a series of resistances which are gradually introduced or cut out of the field-magnet circuit of the dynamo as the ring rotates in one direction or the other, this being effected by means of a small quantity of mercury which remains in the lowermost part of a channel formed in the interior of the ring. These regulating resistances can either be mounted on the frame of the apparatus and be connected to the pins by means of flexible conductors, or they may be embedded in enamel on the ring itself. A commutator in connection with a series of resistances is also provided for enabling the apparatus to work at different P.D.'s. The apparatus is capable of maintaining the P.D. within 0·5 per cent. of the normal, and can also be used with alternating currents.

C. K. F.

Starting Monophase Induction Motors. R. Arno.

(L'Éclairage Électrique, 1897, p. 390.)

The method described consists of:—(1) Inserting, during the first moment of starting, a resistance of a proper value in each elementary winding of the rotor; this is chosen so as to make the whole resistance of the corresponding circuit slightly less than $2 \pi n$ L, L being the inductance of the circuit, and n the frequency of the current.

(2) Impressing on the rotor a very small initial velocity, such as is maintained by rotating the pulley by one quarter turn, or giving a pull to the belt.

(3) Reducing the additional resistance to nothing as the maximum speed is attained.

Tests on three motors of 12, 25 and 110 HP. respectively seem to show that when started in this way, the starting-current is much the same as the full-load current, which is a great recommendation, since monophase induction-motors started by means of an initial rotary-field often require four or five times their full-load current at start.

W. G. R.

First Cost of Transformers. G. ADAMS.

(Electrician, 1896, p. 112.)

The transformers considered are all of the closed magnetic-circuit type, and built for outputs varying from 3 to 10 kilowatts. The frequency of the supply-current is taken as 100; the induction in the core as 3,500 lines per square centimetre; the primary potential difference 2,000 volts; the secondary potential difference 100 volts; the price of copper 10*d.* per lb., and the price of iron as 4*d.* per lb.

W. G. R.

Constant Speed-Motors. W. BAXTER.

(Electrical World, vol. xxx., 1897, p. 633.)

This Paper contains the following practical directions for ascertaining the field-winding of a differentially-wound constant-potential motor. Using an experimental coil on the field-magnet, adjust the exciting current until the required speed is obtained, the motor running light. Next put on the full load, and reduce the exciting current until the same speed is reproduced. From the number of turns on the exciting coil and the current, we at once obtain the ampere-turns to be provided by the shunt and series coils respectively.

A. H.

Setting up Large Generators. G. T. HANCHETT.

(Electrical World, vol. xxx., 1897, p. 665.)

The armatures of large multipolar generators are either lap-wound or else wave-wound. The latter winding is mainly used in high-voltage machines (500 volts or more), the former in low-voltage ones. If a wave-wound armature gives trouble on account of excessive heating caused by a local current, this can only be due to some defect in the armature itself, for any want of symmetry in the field would affect the two armature circuits equally. With a lap-winding, however, the armature may be perfect, and yet the machine may refuse to work satisfactorily, some sections of the winding carrying more current than others, or a section of high voltage supplying current to one of low voltage, thus driving the latter as a motor (this latter action is called "bucking"). Such troubles may be caused by: (1) the field poles not being magnetized to the same intensity; (2) the armature not being truly concentric with the field. By connecting an ammeter in series

with any brush, it is not difficult to ascertain whether the corresponding section of the armature carries its fair share of the load. Difficulties arising from unequal magnetization of the poles are generally due to unequal ampere-turns on the exciting coils, and may be caused by a defect either in a shunt-coil (in which case the armature will heat when running on open circuit), or in a series-coil (when there will be a tendency to "bucking" at full load). A very simple method of finding the defective coil consists in separately exciting the machine and ascertaining the fall of potential over each coil; if the coils are wound with the same size of wire, they should have approximately equal resistances. In setting up large generators, the field is generally adjusted in position by means of a taper-gauge, the same clearance being allowed between each pole-piece and the armature. In most cases this yields satisfactory results, but a further adjustment may be necessary. The field having been aligned as far as possible by means of the taper-gauge the machine is excited, and the electromotive force contributed by each section is ascertained. If the electromotive forces so obtained are plotted at equal angular distances in a polar diagram, and if the diagram exhibits symmetry, any want of equality is due to lack of alignment, and the defect is easily remedied; but if the diagram is distorted, then in all probability the defect lies in one of the exciting coils. The accurate adjustment of the field is a very tedious process, as the field has to be rigidly bolted down after each change of position; the adjustment is, however, made once for all, and then the relative position of the field and bed-plate is marked in two places with a cold chisel.

When a defect has to be remedied and the type of armature-winding is unknown, it may be ascertained in some cases by noticing the relative direction of the end-connectors. Frequently, however, these are covered with canvas, and the best plan then is to send a small current through the armature, and by means of a low-reading voltmeter ascertain the P.D.'s between one of the brushes and all the points where brushes might be placed with a lap-wound armature. From the voltmeter readings the nature of the winding may be inferred.

A. H.

Life of Incandescent Gas-Mantles. E. A. Medley.

(Electric Review, 1897, p. 824.)

The Author gives the results, in the form of curves, of careful tests of various incandescent gas-mantles. These show that in all cases there is a rapid falling-off in light-giving power (in some instances, however, a slight initial rise is observed). Most of the mantles exhibit a deterioration of from 40 to 60 per cent. of their

initial candle-power after 500 hours' use. The best results are obtained with the "Stabil" mantle, of German make, which after 500 hours' use retains about 75 per cent. of its initial candle-power.

A. H.

Schuckert & Co.'s Arc-Lamp.

(Elektrotechnische Zeitschrift, 1897, p. 495.)

This lamp comprises a rocking-frame carrying a train of wheels having, on the first arbor, a drum connected to the movable carbon-holder by a cord or wire, and on the last arbor, a brake-wheel adapted to engage with one arm of a weighted lever which normally rests against a stop in a definite position. The rocking frame rests on horizontal racks by means of toothed wheels, so that, as it rocks, it moves laterally, and thus the motion is made smoother by doing away with an axis turning in stationary bearings. To control the motion of this rocking frame, it is provided at its ends with curved surfaces engaging with rollers mounted on the cores of the regulating solenoids.

C. K. F.

A 10,000-volt Transmission Plant. W. Klug.

(Electrician, vol. xxxviii., 1897, p. 469.)

This is a description of the three-phase plant between Eichdorf and Grünberg. The power is developed at a voltage of 225, transformed up to 10,000 at Eichdorf, and down to 120 volts at a single step at Grünberg. The transmission mains consist of bare copper wire 25 square millimetres in section in the intervening country, and of the same size of india-rubber insulated wire when entering the towns. The lines are throughout protected by lightning-protectors—one for each line wire. The spark-gap is between bent copper strips held on high-pressure insulators. The line is connected to one of these strips and the other is connected to earth. As a further protection from lightning, a barbed wire runs above the line, being fixed to the tops of the poles and earthed at every sixth pole. Experience shows that this system of protection from lightning is efficient.

W. G. R.

Electric Lighting of Vehicles on the Jura-Simplon Railway.

C. JACQUIN.

(L'Éclairage Électrique, vol. xii., 1897, p. 532.)

At the beginning of 1894 electric light had been applied to all the trains on this line; it became a difficult matter to charge all the batteries from the Fribourg station. The Jura-Simplon railway, therefore, took advantage of the large hydraulic station which had been erected at Bienne in 1893; they made this a second charging centre for their batteries. A substation was installed as at Fribourg, serving for lighting purposes as well as for charging accumulators. The central station at Bienne was installed by the firm of Lahmeyer of Frankfort, and obtains its power from a 50-metre water-fall driving two turbines of 250 HP., each working two three-phase generators of 65 kilowatts each. The power at 80 volts provided by the generators is transformed in the station to a pressure of 1,800 volts, and is then sent through two primary circuits consisting each of three bare copper wires.

One of the lines, 2·1 kilometres long, with wires 0·6 millimetre diameter, extends to the Jura-Simplon works 1 kilometre from Bienne, and is there connected to a rotary converter, running as a three-phase synchronous motor, and which itself is used for power purposes as well as for supplying current at 110 volts for lighting. This machine converts 90 kilowatts, 50 to 60 HP. of which is supplied as motive power and the remainder for lighting.

The second primary line, which is 3·2 kilometres long, consists of three copper wires 7 millimetres diameter, and supplies 130 HP., half of which is for the station at Bienne and the other half for lamps and motors in the town, Lahmeyer converters being here used for distribution at 120 volts. These converters consist of a rotating-drum armature and of a single coil 8-pole field. The armature on one side carries three collector-rings for the high-tension current and a commutator on the other side. The high-tension winding is placed in slots in the armature, and the low-tension winding over this. The two windings are separated by a copper earth shield. The converters, as in the case with synchronous motors for polyphase alternating currents, can start alone. If the field be unexcited and the continuous-current side disconnected, and the high-tension side alone be closed, the motor will run up to speed owing to reactions on the pole-pieces, and under these conditions will have an appreciable torque. The converter can be started in this manner in two minutes. The converters are, under some conditions, started as shunt-motors from the continuous-current side, in which case a phase-indicator has to be employed. A part of the continuous current passes to twelve battery-charging circuits. The batteries are removed from the railway-carriages for charging purposes. The original cost of maintenance of 650 batteries, as contracted for by the Société de

Marly, varied from 23 to 25 francs per battery. The Company then undertook the maintenance of the batteries themselves.

The arrival and departure of all the accumulator boxes is recorded in a register. When fully charged, the voltage of nine cells must not amount to less than 19 volts. The batteries are enclosed in three-chamber ebonite boxes protected by an outer wooden case. As in Switzerland the trains do not run after midnight, the batteries can be completely recharged in nine hours. There are 425 batteries in use and 250 batteries kept as a reserve. The lamps, owing to their low voltage, cost 2½ francs each, and their life varies from 300 to 600 and 700 hours.

The central stations mentioned above supply power by meter at the low rate of 0·05 franc per HP.-hour, or 0·067 franc per kilowatt-hour. A single battery supplies current to four 10-candle-power lamps for 1,000 hours each year; and the total cost of maintenance amounts to only 0·0031 franc per lamp-hour of ten candles.

Taking into account the efficiency of converters and accumulators, the expenditure of 30 watts for a 10-candle-power lamp is very low as compared to the price of gas or oil. The Jura-Simplon railway is, however, acknowledged to be working under exceptionally favourable circumstances. It may be said that the greater the railway system the greater the cost of electric lighting.

The Author concluded by the statement that when the applications of electric lighting are restricted to particular cases possessing favourable conditions of working such as the above, then many difficulties are eliminated, and this mode of lighting may then well compete with the other systems.

L. J. S.

Accumulator Traction at Ostend. E. Piérard.

(L'Électricien, 1897, p. 305.)

The cars are constructed to carry fifty persons, with seats (inside only) for twenty-four. The weight, unloaded and without accumulators, is 7½ tons. That of the accumulators is not given; but it is to be inferred that the weight somewhat exceeds 2½ tons. The truck is carried on four wheels, and is furnished with two 18-kilowatt Westinghouse motors, coupled to the axles by single-reduction gearing of 1 : 5. The battery consists of 108 cells contained in twelve boxes, which appear to be placed beneath the seats. The capacity amounts to 140 ampere-hours at a discharge of 50 amperes. The time required for charging varies from three-quarters to two hours according to circumstances, the necessary current being supplied by a steam belt-driven Westinghouse dynamo. All active material falling from the positive plates is carefully collected and reapplied from time to time. Up to the

present, the running expenses have been low. The coal consumed amounts to 5·1 lbs. per car-mile, and the tractive force is said to vary from about 18 lbs. per ton at starting down to 9 lbs. at a speed of 11 miles per hour on Vignole rails.

W. R. C.

Power Transmission. C. P. Steinmetz.

(Electrical World, New York, vol. xxx., 1897, p. 586.)

The Author gives a detailed account of the electrical plant for the transmission of power from Mechanicville to Schenectady, a distance of about 18 miles. The features of interest are:—(1) the generators, which are three-phase alternators of the revolving field type generating direct at 1,200 volts, thus obviating the necessity of step-up transformers, and (2) the use of synchronous motors and rotary converters at the receiving end of the line. The synchronous motors are adopted in preference to induction-motors, on account of the control they give over the power-factor of the plant.

W. G. R.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1897–98.—Part II.

N.B.—Titles in italics refer to Original Papers, and those selected for printing only are further distinguished by the suffix "(S.)" or "(St.)," the latter denoting Students' Papers. Abstracted Papers are not so indicated.

LONDON:
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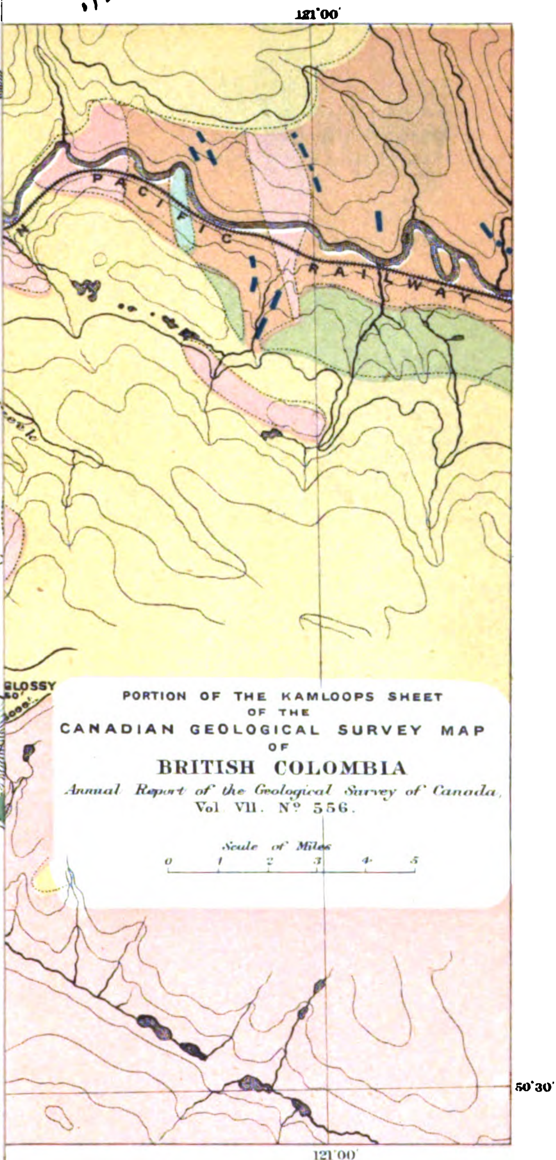
EAT LAND-

11208

PLATE. 1.

Fig: 2.



CARBONIFEROUS

E CREEK STONES | FORMATION LOWER | PLUTONIC ROCKS | OBSERVED LIMESTONE OUTCROP

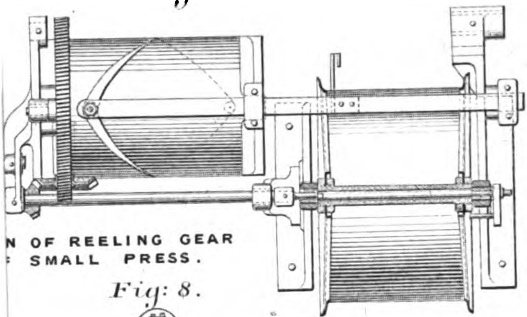
1 Inch = 1 Mile

Minutes of Pro

THOS KELL & SON, LITH. LONDON

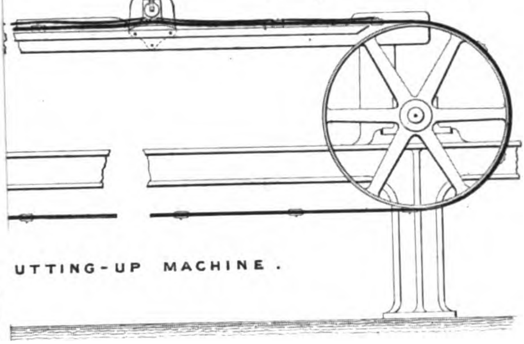

MAC

Fig: 5.

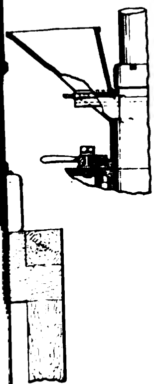


N OF REELING GEAR
SMALL PRESS.

Fig: 8.

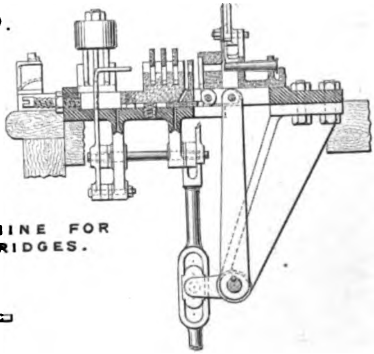


UTTING-UP MACHINE.



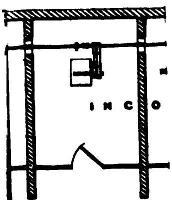
IATE

Figs 9.

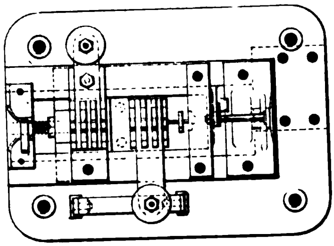


ING MACHINE FOR
FLE CARTRIDGES.

10.



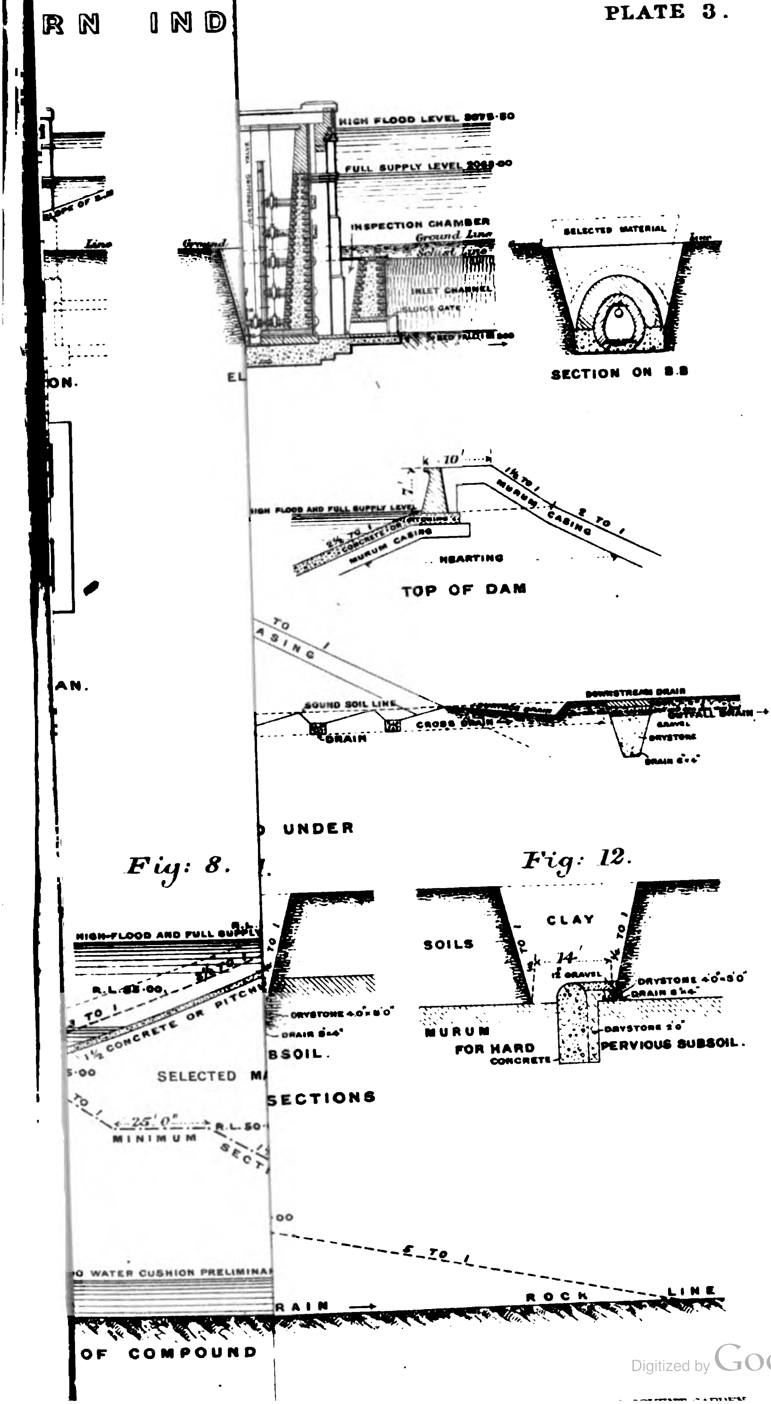
ORDITE FACT

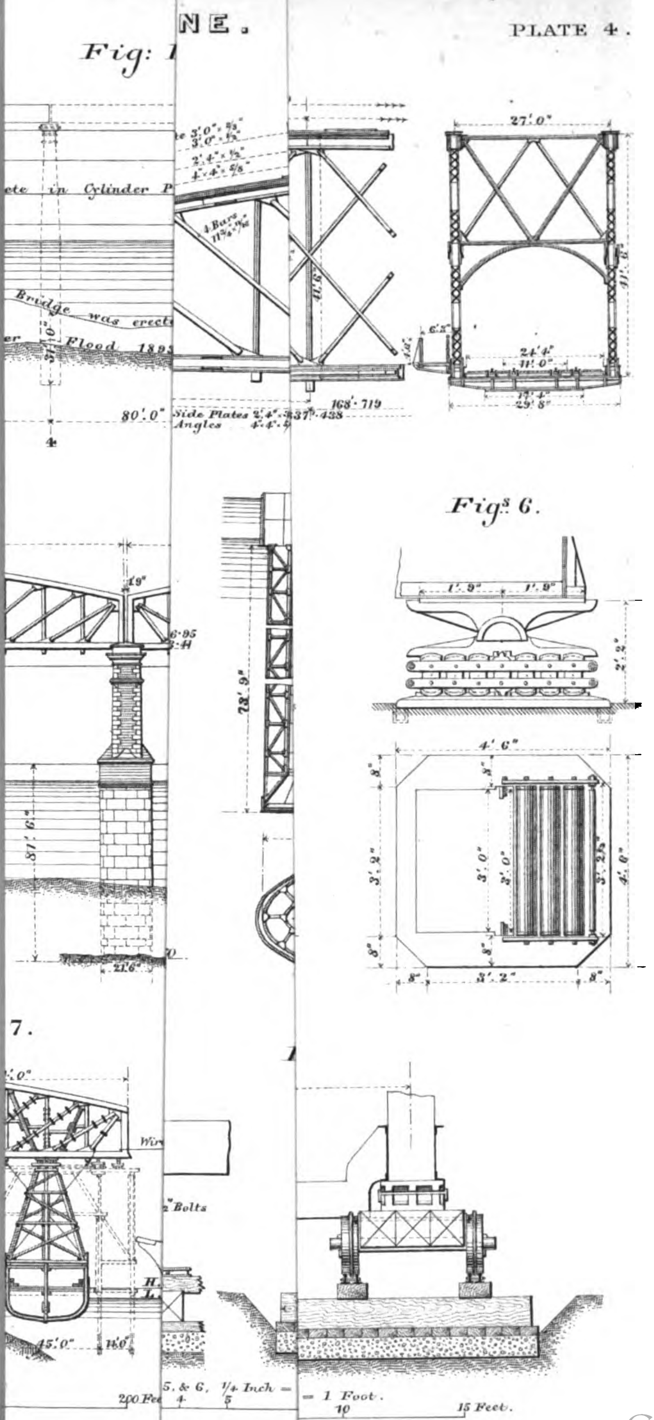


PLAN.

HOS KELL & SON, LITH LONDON.

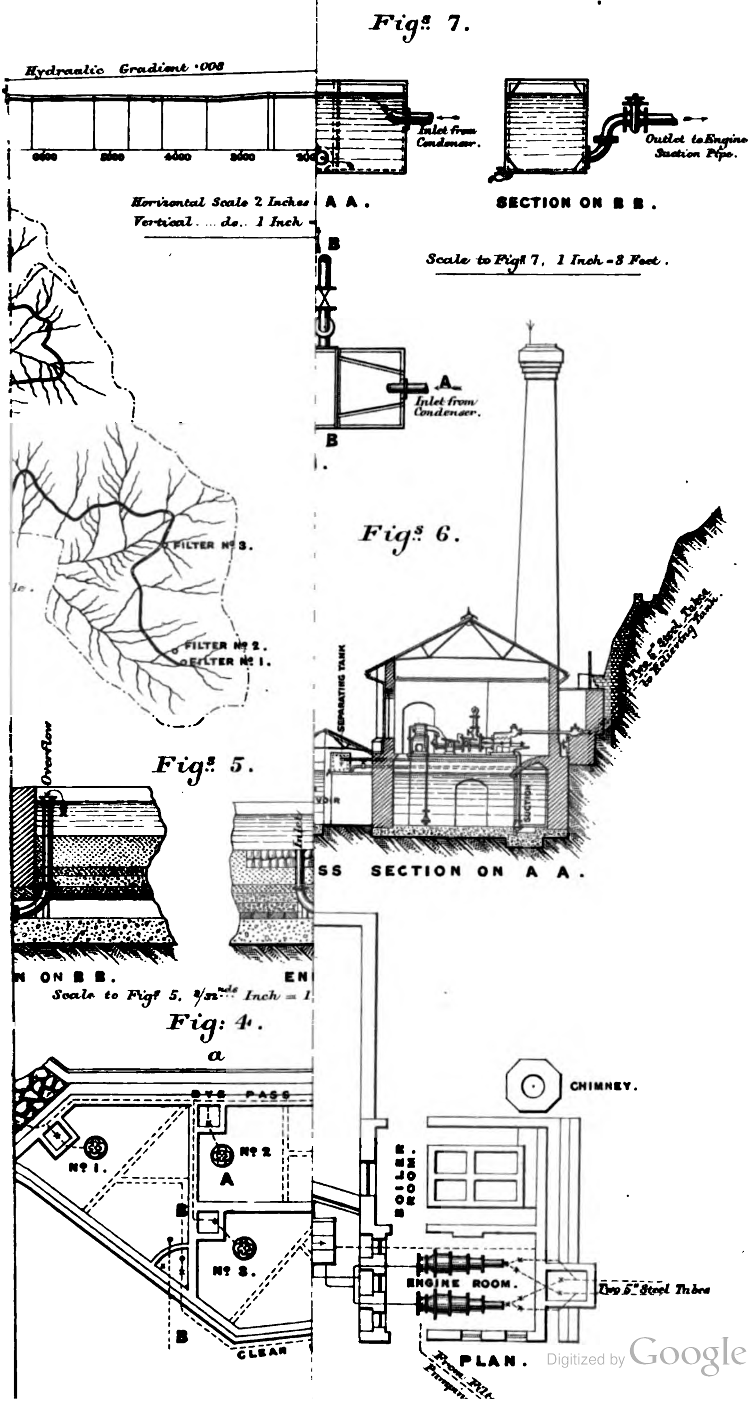
PLATE 3.


RN IND
HIGH FLOOD LEVEL
FULL SUPPLY LEVEL
INSPECTION CHAMBER
Ground Line
Schist Line
INLET CHANNEL
SLUICE GATE
EL
SELECTED MATERIAL
SECTION ON B.B
HIGH FLOOD AND FULL SUPPLY LEVEL
CONCRETE OR PITCHING
MURUM CASING
HEARTING
TOP OF DAM
SOUND SOIL LINE
DRAIN
CROSS DRAIN
DOWNSTREAM DRAIN
OUTFALL DRAIN
GRAVEL
DRYSTONE
UNDER
Fig: 8.
Fig: 12.
CLAY
SOILS
14′
GRAVEL
MURUM
FOR HARD
CONCRETE
PERVIOUS SUBSOIL.
SELECTED
MINIMUM
SECTIONS
WATER CUSHION PRELIMINA
ROCK LINE
OF COMPOUND


NE.
PLATE 4.
Fig: 1
ete in Cylinder P
Bridge was erect
Flood 189
37'0"
80'.0"
Side Plates 2'.4"
Angles 4'.4"
168'.719
27'.0"
24'.4"
11'.0"
29'.8"
6'.2"
Figs 6.
1'.9"
1'.9"
2'.2"
4'.6"
3'.2"
3'.0"
3'.2½"
4'.6"
8"
19"
6·95
73'.9"
81'.6"
21'.6"
7.
45'.0"
14'.0"
"Bolts
5. & 6, ¼ Inch = 1 Foot.
200 Fe
4
5
10
15 Feet.

SIMLA WATE

PLATE 5.



ALLA WAT

PLATE. 6.

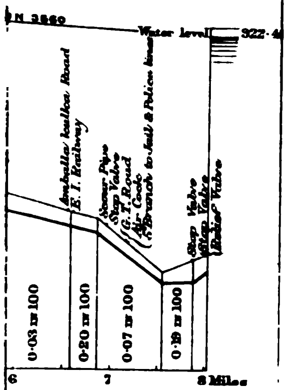
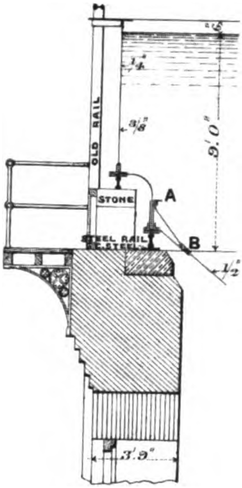
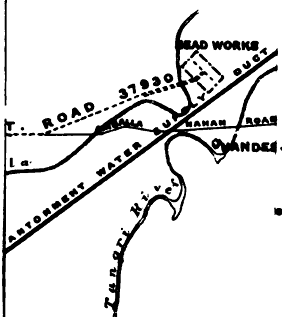
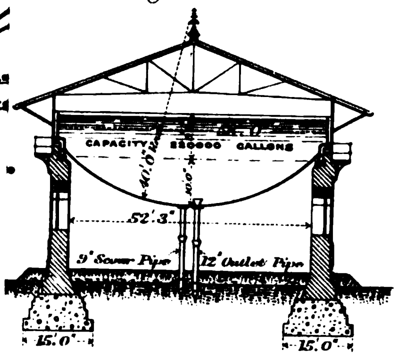


Fig: 8.





Figs: 7.



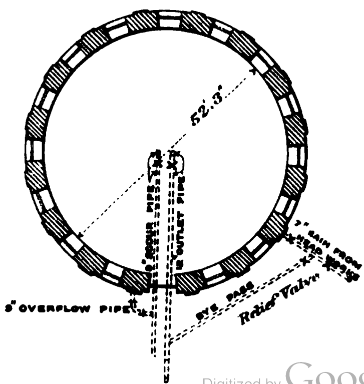


Fig: 1. 1/2 Inch — 1 Mil
" 2. 1/2 Inch — 1 Mil
" 3. 1 Inch — 200 Fee
" 4. 3/32 Inch — 1 Foo
Figs: 5&6. 3/4 Inch — 1 Foo
" 7. 1 Inch — 40 Fee
Fig: 8. 1/8 Inch — 1 Foo